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OBJECT AND SPATIAL SUBSYSTEMS IN MENTAL IMAGERY: BEHAVIORAL INVESTIGATIONS

by

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Date: April 13, 1994

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Gail R. Marsh

Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor of
Philosophy in the Department of Psychology
in the Graduate School of
Duke University

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ABSTRACT
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ABSTRACT

Recent evidence indicates that mental imagery comprises independent object and spatial subsystems. The experiments reported here are behavioral studies of these subsystems. Experiments 1 and 2 used the selective interference paradigm to determine whether these subsystems could be behaviorally dissociated. In Experiment 1, subjects listened to descriptions of spatially arrayed objects as they performed an object or spatial interfering task. Recall of the descriptions was expected to demonstrate selective interference of item names or spatial relations as a function of interfering task, however this result was not found.

In Experiment 2, subjects indicated whether sentences read in either a spatial or a nonspatial format were true or false. Sentences required either object, spatial, or no imagery. The spatial presentation differentially slowed verification time for high imagery sentences compared to abstract sentences. The prediction that the spatial format would selectively slow verification time for spatial versus object imagery sentences did not obtain for all subjects, however subjects of lower spatial ability showed this pattern of results.

Experiments 3-5 isolated one contribution of spatial imagery to memory: Its ability to preserve the sequential order of events. Pictures were presented either all in the same location or in different locations. When items in the spatial condition appeared in consecutive locations (Experiment 3), there was no effect on amount recalled, but subjects made fewer sequencing errors. No benefits of the spatial presentation were found with nonconsecutive locations (Experiment 4), presumably because subjects could not remember the order of locations in which the stimuli

appeared. When retrieval cues informed subjects of the sequence of locations in which the stimuli had appeared (Experiment 5), subjects were able to use the nonconsecutive locations to aid in sequencing.

These studies are interpreted in terms of the anatomical underpinnings of the spatial and object systems. It is argued that connections between these systems make it difficult to separate them through selective interference. Nevertheless, Experiments 3-5 indicate that spatial imagery functions to maintain temporal order information. The two systems therefore appear to serve different and complementary roles in memory.

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Introduction

The similarity between vision and visual imagery has long supported speculation that these processes might share a common neural substrate. The theory put forth by Hebb (1968) explained the occurrence of mental images as the "central activation" of some of the same mechanisms that are normally activated by sensory input. This basic premise has been adopted by a number of theorists, yet despite its intuitive appeal and the variety of studies aiming to confirm the nature of the representation, conclusive behavioral evidence for the visual nature of imagery was not found.

The recent resurgence of interest in imagery is largely due to the refinement of physiological techniques that provide a more direct means of studying an inherently (and at times "unacceptably") subjective phenomenon (Paivio, 1971). The application of these techniques simultaneously freed imagery research from the subjectivity of introspective methods and confirmed a theory that gained much of its appeal from introspection, for it yielded evidence that the visual areas of the brain are active during imagery tasks.

A second line of evidence was also critical. Case reports confirmed that damage to the visual areas of the brain, specifically the occipital cortex, posterior parietal cortex, and inferior temporal cortex often produced not only visual deficits, but imagery deficits as well. From the neuropsychological findings another important conclusion also emerged: It was shown that imagery, like vision, comprises at least two separate, largely independent subsystems; what had been subsumed under the term "imagery" are two related but distinct capacities subserved by partially distinct neural pathways.

The experiments reported in this thesis are behavioral studies of these two

imagery systems. In the first chapter, evidence for object and spatial systems in vision and imagery is reviewed. This chapter also introduces a behavioral paradigm that has been used extensively in imagery research, the selective interference paradigm, and interprets the selective interference literature in terms of the object/spatial distinction. Experiments I and II use the selective interference paradigm to determine whether these two systems can be behaviorally dissociated. Experiments III, IV, and V address the role of spatial imagery in preserving the sequential order of events in memory.

Object and Spatial Vision

In the late 1960's, the findings of a group of researchers, who had been working independently, converged on a distinction between two types of visual mechanisms, one specialized for spatial orientation, and the other for identifying visual stimuli (Ingle 1967; Schneider 1967; Held 1968; Trevarthen 1968). They wrote: "In short, we were making a distinction between *what* an organism sees and *where* he sees it." (Held, Ingle, Schneider & Trevarthen, 1967, p. 42). Schneider (1967) reported that, in the golden hamster, the mechanisms for orienting in space could be dissociated from those involved in identifying objects: Ablation of the visual cortex impaired pattern discrimination, while ablation of the superior colliculus decreased orienting responses to both visual and auditory stimuli.

A similar division of mechanism was later confirmed in primates, though the capacities were localized in cortical areas (Pohl 1973; Ungerleider & Mishkin 1982). Ungerleider and Mishkin argue that primate vision is subserved primarily by the geniculostriate system, i.e., by projections from the lateral geniculate nucleus of the thalamus to the primary visual cortex. They nevertheless retain the terms "what" versus "where" to describe two pathways that begin at the primary visual

cortex in the occipital lobe and diverge to different cortical areas: The dorsal pathway through posterior parietal cortex is involved in visual-spatial processing and the ventral pathway through inferior temporal cortex is involved in object recognition (see Appendix A).

In primates, there is evidence that the functional division may begin in two types of retinal ganglion cells and extend through the lateral geniculate where magnocellular and parvocellular layers, differing in their neural response properties, form the basis of the division evident in the higher visual areas (Livingstone & Hubel, 1988). Livingstone and Hubel point out that at each level of processing the segregation of cells that code different aspects of a visual stimulus becomes more defined: The two types of ganglion cells that are "intermixed" in the retina project to different layers of the lateral geniculate nucleus, and ultimately to association areas in different lobes.

Livingstone and Hubel claim that the separation of these different channels could be observed in psychophysical experiments using isoluminant stimuli. They reason that perception of depth and motion are compromised under conditions of isoluminance because the magnocellular pathway, which is specialized for analysis of depth and motion, is not selective for wavelength, but is functionally color blind. Therefore, when brightness information is removed and the stimulus defined only by differences in wavelength, perception of depth and motion is impaired.

Unfortunately, this claim has not held up to more rigorous testing. Logothetis, Schiller, Charles and Hurlbert (1990) demonstrated that not only motion and depth perception but also texture perception, which is supposedly carried by the color selective system, is impaired when stimuli are isoluminant. Moreover, the finding that motion and depth are discriminated above a chance level at

isoluminance indicates that the magnocellular system is capable of utilizing color information. Single-unit recordings from magno- and parvocellular layers of the lateral geniculate corroborate the behavioral findings by demonstrating that the responses of both types of cells diminish but do not cease at isoluminance. These findings do not disprove the existence of separate processing channels, but indicate that though each system is specialized for the analysis of specific properties of a visual stimulus, some ability to process other aspects is retained.

The properties of the two cortical systems are further described below. Since it is at the cortical level that imagery and perception employ the same neural mechanisms, the nature of the cortical division is most pertinent to an understanding of mental imagery.

The Occipital-Parietal Pathway

In posterior parietal cortex visual information regarding movement and location is integrated with information from somatosensory areas to construct a supramodal spatial representation. Lesion studies with primates have implicated this region in discerning the spatial relationships between objects by demonstrating that removal of this area produces deficits in a task in which the target stimulus is designated by its distance from a neutral object (Pohl, 1973). It has been suggested that analysis of the relationship between the self and objects is accomplished by a separate system (Pohl, 1973; Butters, Soeldner & Fedio, 1972), but the deficits that follow damage to the posterior parietal cortex seem to encompass both egocentric and extrapersonal spatial analysis. In humans, the diverse effects of damage to the posterior parietal cortex include visuospatial disorientation, unilateral neglect, reading and writing disorders, misreaching for visual targets, and a variety of eye movement disturbances such as difficulty maintaining, redirecting, and

relinquishing fixation, and difficulty tracking a target (Hyvarinen, 1982).

The posterior parietal cortex seems to be involved in localizing stimuli in space and in at least some aspects of spatial attention (Posner & Petersen, 1990). It could be argued that some of the deficits cited above are localization deficits, while others are more appropriately classified as deficits in spatial attention. That issue is beyond the scope of this paper and though it may be necessary to distinguish these at some point, for now they will be considered "... different reflections of a single, supramodal spatial disorder.... " (Ungerleider & Mishkin, 1982, p. 555).

The impairments in visually guided reaching and pointing that are associated with damage to the posterior parietal lobe suggests that one of the primary functions of this area may be to relate visual and somatosensory information for the purpose of guiding movements, especially hand movements, towards targets (Goldberg, 1982). Hyvarinen speculates that in evolution there was a substantial increase in the size of the posterior parietal lobe when the shift to bipedal locomotion freed the hands and Critchley (1953) wrote:

> The hand plays a peculiar role in human ecology, being part of the anatomy which is usually exposed; which is most of the time within the view of the individual... The hand is largely an organ of the parietal lobe. (1953, p. 210 also quoted in Hyvarinen (1982), p. 63)

In area 7 of the posterior parietal cortex, the responses of neurons driven by both visual and somesthetic stimuli are typically specific either to a certain location in space or to a direction of movement (Hyvarinen & Poranen, 1974). A large number of cells in this region are driven by either looking or reaching toward a specific location. These cells responded to the presentation of a raisin both when the subject reached for the raisin with its view blocked and when it could see the raisin but had its arms restrained. The responses of other neurons were

contingent on the direction of motion. These cells might, for example, respond when the subject moves its arm up to reach for a reward, but not when it moves it arm down. Moreover, though visual stimulation alone was insufficient to activate this type of cell, its responses were reduced when the eyes were covered. Hyvarinen and Poranen also found that many of the cells in area 7 are activated by looking at a visual stimulus or by manual reaching, tracking, or manipulating. A smaller number of cells are responsive to stimuli in more than one modality. Goldberg (1982) notes that such a cell conveys an "ambiguous message" since "It describes the existence of a visual or tactile stimulus and its retinal or somatic location, but can give no other detail" (p. 294).

The Occipital-Temporal Pathway

In the ventral pathway from the primary visual cortex in the occipital lobe to the inferior temporal cortex, the visual details of a stimulus are separately analyzed in the prestriate and posterior temporal areas along such dimensions as size, texture, shape and color. These neurons in turn converge on inferior temporal neurons which store this information. Mishkin (1982) writes:

> It is this postulated convergence or integration of visual inputs in area TE that makes it particularly well suited to serve not only as the highest-order area for the perception of visual stimuli but also as the storehouse for their central representations. (p. 87)

These neurons in the inferior temporal cortex differ from those in posterior parietal cortex in being unresponsive to auditory or somesthetic stimuli, and having large receptive fields that "invariably" include the fovea (Gross, Rocha-Miranda & Bender, 1972). In addition, they are responsive to stimuli across large portions of the visual field, in a sense ignoring the location of the stimulus. The role of the inferior temporal cortex in associating incoming sensory information with a stored

representation suggests a reason for the evolution of an architecture in which the features of an object and its location are separately represented: The division may enable stimulus equivalence across retinal translation -- the ability to recognize an object regardless of its position in the visual field (Mishkin, Ungerleider & Macko, 1983).

Studies with primates confirm the role of the ventral pathway in object recognition. The delayed matching (or non-matching) to sample task allows discrimination and recognition ability to be assessed. In this paradigm, subjects are trained to respond to a sample stimulus, which then remains visible for a few seconds. Following a brief retention interval two stimuli are displayed and the subject is rewarded for choosing either the one previously presented (matching) or the novel stimulus (non-matching). In contrast to the impairment in pattern discrimination which follows a lesion restricted to the posterior region of the temporal lobe, in area TEO, lesions of the anterior portion of the inferior temporal cortex, area TE, referred to by Mishkin as the "storehouse" for visual representations, produce object recognition impairments, but have little effect on pattern discrimination. The deficits produced by lesions of area TE may therefore be comparable to associative visual agnosia, i.e., a recognition deficit in the absence of a more general intellectual impairment and despite relatively preserved sensory analysis.

The role of the inferior temporal cortex in object recognition is corroborated by two other findings. First, that applying electrical stimulation to this region during the delay period and particularly during the matching period produces significant deterioration in performance on a visual recognition task, but has a relatively small effect when the sample stimulus is displayed during the matching

period (Kovner and Stamm, 1972). Second, that neurons in this area are active in the retention interval of a delayed matching to sample task, and that their activity ceases once the match is made and the subject is no longer required to remember the target (Fuster and Jervey, 1981).

The distinction between a system that encodes the spatial relations between objects and a system that subserves object analysis and recognition may seem counterintuitive since "... shapes and patterns are defined by the spatial arrangement of their parts" (Schneider, 1969, p. 895), yet the dissociation is well documented. A patient with damage to the posterior parietal area may be able to recognize an object, and yet be unable to locate it in space, as evidenced by errors in pointing to a visual target. Conversely, damage to the occipital-temporal region may produce profound visual recognition impairments, but leave the patient's ability to locate an object intact. The patterns of deficits seen in patients with damage to the visual areas of the brain are consistent with the separation of function that Schneider observed, namely that the analysis of spatial relationships between parts of an object is not accomplished by the same system that analyzes spatial relationships between objects.

Object and Spatial Subsytems in Mental Imagery

Imagery may be defined as a short-term memory representation in which a pattern of activity like that produced by a visual stimulus is evoked by "top down" processes. Visual imagery is most often associated with an experience that is similar to seeing, but occurs "in the absence of the appropriate sensory input." (Kosslyn, 1987). The desire to explain the phenomenal experience that often accompanies imagery has intensified a long-standing debate on the nature of the representation. The debate centers on whether images represent information in a

descriptive, amodal format or in an array format and, among proponents of the analog view, whether it is best characterized as distinctly visual or simply spatial (Farah, Hammond, Levine and Calvanio, 1988).

Early Indications of a Divided System

Behavioral studies seeking to characterize imagery as visual or spatial were largely inconclusive. On the other hand, the finding that emerged from factor analytic studies of different tests of imagery ability was that such tests tap at least two relatively independent factors, the ability to manipulate objects in space, and the tendency to describe one's images as clear and detailed (Garro 1982; Lorenz & Neisser, 1985). These studies demonstrated that performance on objective tests, such as mental rotation, is not predicted by subjective ratings of vividness.

Other suggestions that imagery might be a componential system exist in the literature, but for the most part these were not actively pursued. For example, Paivio (1971) refers to static versus dynamic images but does not consistently distinguish between them. There are at least two early researchers, Brian Byrne and Wiel Janssen, who were sensitive to a distinction between spatial and nonspatial components in imagery, and whose empirical work was motivated by this distinction. Most notably, Janssen's (1976 a) book entitled "On the Nature of the Mental Image", though obscure and largely uncited, is devoted almost entirely to this thesis. Janssen reviewed the findings of Ingle (1967), Schneider (1967; 1969), and Trevarthen (1967), and concluded that in addressing the nature of imagery

> ...it is absolutely necessary to qualify this hypothesis by distinguishing between ... spatial features indicating basically *where* things are, and nonspatial (sensory) features containing information about *what* things are. (p. 2)

He maintained that a stimulus is encoded through a series of eye movements or

covert shifts of attention and intermittent fixations. Both the pattern of eye movements and the features observed at each fixation are recorded. The object, and the constructed representation is therefore decomposable into sensory features and the spatial relations among them. Janssen proposed an interpretation of the interference literature that, like the one developed here, is based on the idea that the perceptual division is paralleled in imagery.

The convergence between these early suggestions of distinct components in imagery and more recent evidence for a structural division is especially striking in light of the fact that, with the exception of Janssen's work, the behavioral evidence was interpreted without reference to the physical substrate. Once the involvement of the visual system in mental imagery was ascertained, however, it became immediately apparent that the proposed subsystems might roughly parallel a division that was known to exist in the visual system.

Object and Spatial Imagery "Defined"

Recent advances now make it possible to begin defining the two subsystems with regard to the nature of the physiological substrate, which in turn may enable a more rigorous classification of imagery tasks. Some investigators, e.g., Farah and her collaborators, refer to these two subsystems as visual and spatial imagery. The use of the term "visual" to refer to a type of imagery may introduce confusion and also implies that the "spatial" system is nonvisual. Here I follow Ungerleider and Mishkin's (1982) terminology for the perceptual division by referring to these as "object" and "spatial" imagery.

Complete definitions of the imagery subsystems are unavailable since they have only begun to be explored, and it is probably advantageous to await converging evidence from behavioral and physiological measures rather than

assigning these systems a priori definitions. The working assumption in this paper, based largely on the nature of the perceptual division, is that object images represent the visual appearance of individual objects and are necessarily tied to the visual modality while spatial imagery provides a system for specifying the location of an imaged object relative to other objects (cf. Farah, Hammond, Levine & Calvanio, 1988). More recently, it has been suggested that spatial memory may also have an attentional component (Smyth & Scholey, 1993). In addition, the last three experiments in this thesis suggest a role of spatial imagery in maintaining information about temporal order.

Within the past decade, a number of different methods have been used to investigate the neural bases of mental imagery. In the main, these studies indicate that imagery relies on a number of different brain areas, and moreover, that the particular areas subserving imagery depend on the nature of the task. A complete review of these findings can be found in Farah (1989). For the purposes of this paper, the most important findings concern the dissociation between object and spatial imagery.

Evidence for Two Imagery Systems.

Studies of brain-damaged patients

Though the arguments are based to a great extent on previously existing data, Farah and her coworkers were the first to investigate the relationship between imagery and perceptual deficits in a theoretical framework. Based on the selectivity of imagery deficits that follow damage to different areas of the brain, they have argued persuasively for the existence of spatial and object subsystems in imagery. A review of published case reports confirmed what they observed in their own testing of two patients: First, although imagery and perceptual deficits do not

always co-occur, when the deficits include both processes the abilities that are lost are usually parallel; impairments in object perception and object imagery are commonly associated, as are impairments in spatial perception and spatial imagery. Second, that as with perceptual deficits, spatial and object imagery may be dissociated so that one system fails while the other continues to function normally.

In one patient studied by Levine, Warach, and Farah (1985), occipital-temporal damage produced deficits in face recognition (prosopagnosia), deficits in identifying photographs of animals and occasionally objects, and deficits in the ability to categorize colors by sorting. Object and color imagery were similarly impaired as indicated by the patient's inability to describe from memory the appearance of people, animals, and some objects. For example, he could not state the color of the inside of a watermelon nor could he describe differences between the appearance of a lion and a bear. In addition, the patient could not accurately draw from memory, though he could draw an object in the room. Levine et al. observed, however, that the patient's impairments were restricted to object perception and imagery. Spatial perception and imagery were preserved, enabling him to accurately reach for a visual target and make discriminations on the basis of orientation, as well as provide directions to familiar locations.

More formal testing of the patient's ability to perform tasks requiring imagery confirmed that the imagery deficits were specific to certain types of tasks: He performed normally on spatial imagery tasks, e.g., mental rotation and a mental scanning task, but was impaired on tasks that required imaging animals, colors, common objects, and the shapes of U.S. states (Farah, Hammond, Levine, & Calvanio, 1988).

The pattern of spared and impaired functions in a second patient with

occipital-parietal damage provides a double dissociation between object and spatial imagery (Levine, Warach, & Farah, 1985). In this patient, the spatial system was affected, while the object system remained intact. The perceptual impairments he exhibited included misreaching for and colliding with objects, and difficulties in writing, reading, drawing, fixating stationary objects, and tracking moving objects. Errors made in determining which of two objects was closer or below or to the right of another were indicative of the difficulty he had in discerning spatial relationships between objects. In contrast, object and color perception were relatively unaffected. If individually presented, objects, animals, faces, and colors were correctly identified. Like the perceptual deficits, the imagery deficits involved the spatial system, affecting his ability to give directions from memory and to indicate the location of objects in the room when blindfolded. Nevertheless, he retained the ability to describe faces and animals from memory, and could state the colors of familiar foods, which suggests that object imagery was relatively intact.

Studies of brain activity

Event-related potential studies. Evidence from event-related potential (ERP) studies provides further confirmation of two imagery subsystems by indicating that the distribution of brain activity varies depending on the imagery task. The ERP technique involves recording from the scalp the electrical activity that is produced in response to a specific stimulus. ERP data is obtained by repeatedly presenting a stimulus, and then averaging the EEG recordings measured from the onset of the stimulus so that random activity is canceled and the component specific to the stimulus is amplified. When the waveforms that emerge are identified as manifestations of specific cognitive processes, ERP data can provide information

regarding the location, timing, and degree of activation of those functions. For the purposes of this paper, ERP data supports the distinction between object and spatial imagery by indicating that the distribution of activity varies with the nature of the imagery task.

Farah, Weisberg, Monheir, and Peronnet (1989) used this technique to compare the effects of imaging the referent of a visually presented concrete word to control conditions in which subjects simply read either concrete or abstract words. A comparison of the three conditions indicates an effect of imagery in a positivity occurring at approximately 700 msec at the occipital and posterior temporal regions.

In contrast, ERP studies of mental rotation have located the primary areas of activity in the occipital and parietal lobes. Stuss, Sarazin, Leech, and Picton (1983) were among the first to apply the ERP technique to mental imagery. Stuss et al. were primarily interested in the semantic processing of visually presented stimuli, and included mental rotation as a non-semantic control for the task of naming objects presented in pictures. In the mental rotation condition, subjects indicated whether two line drawings, one of which was rotated between 45 and 135 degrees, were identical or mirror images. A late posterior negativity occurring between 1000 and 1200 msec and maximally negative at the parietal leads was identified as a physiological marker for the mental rotation process.

Peronnet and Farah (1989) later confirmed the involvement of the posterior parietal region in mental rotation. They compared two tasks that were identical in every respect except the need to rotate the stimulus, and found that a posterior negativity in the 400-800 msec range distinguished trials requiring rotation from those that did not. The identification of this component with the rotation process is strengthened by the finding that its amplitude is linearly related to the orientation of

the stimulus, and thus to the degree to which the stimulus had to be rotated to be imagined in an upright position. In demonstrating a role of the posterior parietal region in mental rotation, these two ERP studies corroborate the finding of Butters, Soeldner, and Fedio (1972), that patients with parietal damage were impaired in their ability to copy a figure as it would appear if rotated 180 degrees.

More recent ERP studies of imagery have been designed specifically to address the possibility that the areas of primary activity depend on the content of the image. To compare the brain activity associated with object and spatial imagery tasks Uhl, Goldenberg, Lang, Lindinger, Steiner, and Deecke (1990), compared the activation patterns produced by imaging three different types of stimuli -- a map, colors, and faces. For all conditions, subjects studied the stimuli to be imaged and later generated the images to an auditory cue. On each trial, a slide defined the type of trial, and the particular stimulus to be imaged was then given verbally. In the "color" condition, subjects were instructed to imagine one of five colors. In the "faces" condition, they were asked to imagine a static, monochromatic picture of a politician's face. In the "map" condition the verbal cue named two locations on the map and subjects imaged the portion of the map linking these. Subjects formed and maintained the appropriate image for a few seconds. Among other analyses, for each condition specific comparisons of the sustained negative waveforms at the temporal and parietal sites were made. As expected, the activity at the parietal sites was greater than the activity at the temporal sites when subjects imaged the map, and conversely, was greater at the temporal sites when subjects images faces or colors.

Cerebral blood flow studies. A second method of assessing brain activity involves measuring blood flow by analyzing the distribution of a radioactive

substance that has been injected into the blood stream. The distribution of the radioactive substance reflects the regional cerebral blood flow (rCBF), which in turn reflects the areas of greatest neural activity. This technique has been used to study such imagery tasks as imagining walking a familiar path (Roland & Friberg, 1985), verifying high imagery sentences and counting the corners of letters (Goldenberg, Podreka, Steiner, Willmes, Suess, & Deecke, 1989) and learning concrete words (Goldenberg, Podreka, Steiner, & Willmes, 1987). The results of these studies are generally consistent with the expectation that spatial tasks would produce activity in the occipital and posterior parietal regions while object imagery tasks would produce activity in the occipital and inferior temporal regions. Specifically, Roland and Friberg (1985) found increased activation of occipital, posterior inferior temporal and posterior superior parietal cortex, as would be expected from a task in which subjects were instructed to imagine walking through their neighborhoods, alternating right and left turns, and concentrating on the appearance of their surroundings. Goldenberg et al. (1987) found that memorizing concrete nouns produced activity in the occipital and inferior temporal lobes, but not the parietal lobes. Inferior temporal and occipital activation accompanied both judgments about the truth of high imagery sentences and a letter corner counting task (Goldenberg et al., 1989).

Goldenberg, Podreka, Uhl, Steiner, Willmes and Deecke (1989) compared the neural activity associated with imaging faces, colors, and a map, but found no differences in the distribution of cerebral blood flow related to the object/spatial distinction. This result stands in contrast to the ERP findings of Uhl et al., but may as the authors suggest, be explained in terms of differences in the sensitivity and temporal resolution of the these methods.

PET Studies. A recent study by Smith and Jonides (unpublished manuscript) used positron emission tomography to compare the brain areas that were activated by object and spatial memory tasks. In the spatial memory task, subjects were briefly shown an array of three dots located on the circumference of an imaginary central circle. After a 3-second interval, a "location probe", consisting of a single outline circle, appeared. Subjects indicated whether or not the encircled location had been occupied by a dot. In the object memory task, subjects were shown two novel geometric figures. After a 3-second interval, a single figure was displayed, and subjects indicated whether or not the probe matched one of the previously shown figures. Each subject participated in one of the two memory tasks and a perceptual control condition. The perceptual tasks were identical to the memory tasks except that they had no storage requirement.

The activity associated with each control condition was subtracted from the corresponding memory condition. The difference images indicate that the brain areas that underlie storage of locations are different from those that underlie storage of objects or patterns: Spatial memory was associated with right hemisphere activation of prefrontal cortex, parietal cortex, occipital cortex, and premotor cortex. In addition, although not statistically significant, the spatial task was associated with increased activation in the homologous areas of the left hemisphere. Object memory was associated with activation of left inferior temporal cortex, left posterior parietal cortex, the anterior cingulate gyrus, and a region in the prefrontal cortex adjacent to that implicated in the spatial task.

These results are broadly consistent with a dissociation between object and spatial imagery. They are also important in acknowledging the role of the prefrontal cortex in mental imagery. Single-cell recordings in monkeys (e.g., Wilson,

Scalaidhe, & Goldman-Rakic, 1993) have implicated the lateral prefrontal cortex in memory storage by demonstrating that neurons in one region of the lateral prefrontal cortex are active during the retention interval of a spatial memory task, while neurons in an adjacent region of the prefrontal cortex are active during the retention interval of an object memory task. Related to this finding, it is worth noting that Hanley, Young, & Pearson (1991) describe a patient who, following subfrontal damage, is able to perform imagery tasks only when the relevant information was stored prior to her illness. When the task requires the generation of new images, her performance is impaired. Future research may determine that prefrontal activation only occurs in tasks which require the formation of new images.

One final comment on the study conducted by Smith and Jonides pertains to the surprising finding that the posterior parietal cortex is activated in both tasks. This result, not directly addressed by the authors, is clearly not predicted by the object/spatial division as delineated by Ungerleider and Mishkin (1982), but foreshadows more recent claims regarding connections between the two pathways (e.g., Zeki, 1993).

In addressing the neuropsychological evidence for a division between object and spatial imagery, a remaining question concerns the extent to which object and spatial imagery are lateralized functions. The traditional conception is that the right hemisphere is specialized for visual-spatial functions and for holistic processing, while the left hemisphere is specialized for language and for sequential, analytic processing. Although this would seem to implicate the right hemisphere in imagery, there is some evidence that image generation is subserved primarily by the left hemisphere (e.g., Farah, Gazzaniga, Holtzman, & Kosslyn, 1985; Farah 1986). On

the other hand, several researchers argue that both hemispheres contribute to this process (see Tippett, 1992 for a review). Evidence for a right hemisphere basis for spatial processing is less equivocal. One possibility is that the two cerebral hemispheres make different contributions to object and spatial imagery. The findings of Smith and Jonides (unpublished manuscript) are consistent with this possibility.

The Selective Interference Paradigm: New Predictions

Much of the research that has been conducted in an attempt to clarify the nature of the imagery representation uses a selective interference paradigm. This paradigm was developed by Brooks (1967), who argued that object evidence for the involvement of the visual system in mental imagery could be obtained by demonstrating modality specific (visual) interference. In his first selective interference study, Brooks demonstrated this effect using the visual task of reading by showing that fewer errors were made in recalling spatial descriptions when subjects listened to the material than when they read it. Conversely, however, when the material to be learned was nonspatial, reading the material improved subjects' performance.

Brooks originally maintained that if visual imagery relies upon the visual system, then "... it should be possible to show that attending to *any* visual stimulus hinders concurrent visualization (p. 299)." An implied corollary is that imagery should not be disturbed by processing in other modalities, such as audition. Contrary to expectations, however, the modality of the perceptual task is not a good predictor of interference effects: Interference does not always occur when the perceptual task is visual and it is sometimes observed even when the perceptual task is not visual. However, if interference reflects the extent to which two tasks engage

the same neural pathway (Kinsbourne & Hicks, 1978), then predictions regarding the conditions of interference between imagery and perception must be revised to account for the division in both the imagery and perceptual systems.

The new prediction can be stated as follows: When the visual task primarily involves processing in the occipital-temporal pathway and the imagery task involves the occipital-parietal pathway, or vice-versa, little or no interference will be observed. Interference will be maximal when the paired tasks compete for processing or neural representation within the same neural system (cf., Tresch, Sinnamon, & Seamon, 1993; also see Janssen 1976a for an early formulation of a similar idea).

Specifically, this implies that spatial imagery will be susceptible to perceptual processing of movement and location in visual and somatosensory modalities, since its substrate is a site of multimodal convergence, but it should not be affected by processing shape, pattern, texture, or color since the neurons subserving spatial coding are not selective for these properties of a visual stimulus. Conversely, processing in other modalities should not interfere with object imagery since the occipital-temporal pathway subserves only visual analysis. Object imagery should be susceptible to interference by a visual task involving analysis of shape, pattern or texture, but not analysis of movement or location.

In some cases, the relative involvement of the two imagery systems may hinge on the manner in which a stimulus is conceived. For example, a matrix of half-filled cells may be processed either sequentially as a path or holistically as a pattern. The predicted effects of a given secondary task would vary accordingly. Similarly, although images of individual objects may be represented by the occipital-temporal system, if the task requires the subject to scan the image so that

parts of the image are sequentially activated and attended, the posterior parietal system may become engaged. In short, as Phillips and Christie (1977) argue, the extent to which an imagery and perceptual task conflict will depend not only upon the modality of the perceptual task, but also upon the processing demands of the paired tasks.

Evidence For Two Imagery Systems From Selective Interference

In general, the literature supports these predictions although the majority of these studies were not designed to support the distinction between spatial and object imagery. The majority of previous studies can be divided into two general classes: 1) early studies designed to show a dissociation between imagery and verbal memory and 2) later studies designed to determine whether the imagery representation is spatial or specifically visual. These studies are supportive of the hypothesis advanced here because it can be shown that, with some exceptions the following generalization holds true: When interference effects are found, the paired tasks are ones that would be expected to rely heavily on the same system. Moreover, a few reported failures to find interference represent attempts to demonstrate interference using tasks that would be expected to rely on different systems.

In considering the interpretations of these studies, however, two general points should be stressed. First, because these studies typically compare the effects of two types of processing on two memory tasks to show some form of an interaction, interference effects are relative and not absolute. They are relative with respect both to the comparison memory task and to the alternate perceptual task. Second, though interpreting the findings of earlier studies requires classifying the imagery and visual perceptual tasks as object or spatial, the classification is

misleading insofar as it implies a strict dichotomy. It is unlikely that visual processing ever occurs exclusively in one of these pathways since every object has a location, and location must be designated by some marker. Nevertheless, it seems reasonable to assume that visual tasks will differentially engage these two systems depending on the amount and type of information that can be extracted from a stimulus. For example, a stationary object may require less processing in the occipital-parietal pathway than a moving object, and the amount of activity in the inferotemporal pathway is likely to be proportional to the visual complexity of the object. It is more accurate to consider these tasks as falling on different points of a continuum.

In some studies the imagery and/or perceptual tasks appear to involve approximately equal contributions of object and spatial processing. For this reason the following studies are not readily interpretable within the framework developed in this thesis: Dean (1984), Elmes (1988), Kosslyn, Holyoak, and Huffman (1976), Newstead and Blackley (1979), Pellegrino, Siegel, and Dhawan (1975), Pellegrino, Siegel, and Dhawan (1976), Sasson (1971), Sasson and Fraisse (1972), and Wicker & Holley (1971).

Most studies are amenable to interpretation within the framework outlined however, and the large number of experiments makes the idiosyncrasies of individual studies less important. The interference studies to be reviewed are divided into two sections based on initial classifications of the imagery tasks. Interference of object imagery is reviewed first, followed by studies of spatial imagery. The chapter concludes with two recent studies that provide direct tests of the hypothesis that interference between imagery and perception is predicted by the object/spatial division.

Interfering With Object Imagery

In this section, the experiments to be considered are those that pair a perceptual task with an object imagery task. Object imagery plays a role in both recognition and recall by representing in working memory the visual properties of individual objects, including shape, pattern, and texture, by a pattern of activity in the occipital-temporal pathway. This system is typically engaged when it is necessary to access information about an object's appearance, particularly subtle aspects of its appearance that may not have been explicitly considered before. For example, an image is probably not required to recall that grass is green, but may be evoked by the question "which is a darker green, a string bean or a pea?"

Interfering with pattern recognition

Images are probably not generated during the response phase of a recognition test (cf. Slee, 1980), however they may function as a temporary buffer during the retention interval. This possibility is supported by data from primates indicating that some inferior temporal neurons remain active during the retention interval of a delayed matching to sample task (Fuster & Jervey, 1981). Also consistent with the role of imagery in a recognition task is evidence from PET that some of the visual regions are involved in memory storage (Smith & Jonides, unpublished manuscript). If a stimulus to be remembered is retained in working memory as an image, then requiring the subject to process visual information during the retention interval may impair performance on a recognition test. Two recent interference studies designed specifically to demonstrate the independence of object and spatial systems have used recognition tasks. A description of these studies is deferred to the end of this chapter. These two aside, only a study by Proctor provides clear evidence for interference of object imagery in a recognition

paradigm.

Proctor (1978) used a task developed by Posner and Keele (1967) in which subjects determine whether two sequentially presented letters are the same or different. Posner and Keele found that time to detect a match is faster when the letters are physically identical than when they are identical in name only, with the response time difference decreasing with increases in the interval up to about 2 seconds. In Proctor's study, subjects added pairs of visually or auditorily presented numbers in the retention interval. Both tasks increased overall time to detect a match, but visually presented digits differentially slowed time to detect a physical match. Neither visually presented digits nor meaningless pattern masks were disruptive when unattended, however, and Proctor concludes that the interference caused by adding visually presented digits results from the need to actively attend to the stimulus.

An experiment by Phillips and Christie (1977) in which digits were presented in the retention interval of a pattern recognition task failed to find modality specific interference effects. Yet, as Logie, Zucco, and Baddeley (1990) point out, their design is incomplete since the effects of interpolated activity on a verbal task were not assessed. When Logie et al. compared the effects of mental arithmetic and an imagery task on verbal and nonverbal memory tasks, the modality specific effect emerged as dominant.

Imagery and verbal learning.

Concreteness and imageability are highly correlated, and these factors are strong predictors in studies of verbal learning. Referring to numerous studies which attest to the relative ease of remembering concrete compared to abstract material, Paivio (1971) proposed that different types of information are more or less likely to

evoke an image and argued that material that is amenable to imaginal as well as verbal coding is more likely to be remembered. He claimed that "...the major effective variable differentiating concrete and abstract words is the availability of referent images (p.95)". Yet the advantage of concrete material cannot be decisively attributed to imageability because of semantic factors that are inextricably tied to concreteness. Other researchers maintain that concrete words more efficiently access a general knowledge base. For example, Schwanenflugel and Shoben (1983) argue that the representation of abstract concepts is less detailed, and perhaps more diffuse, making it difficult to create a supporting context for abstract material. A similar suggestion is made by Jones (1988), who proposed that a "semantic alternative" to imageability is the ease with which a word can be described by "simple factual statements".

Because of the number of dimensions along which concrete and abstract words vary it is not implausible that, contrary to Paivio's claim, in verbal learning the image is epiphenomenal, a correlate of concreteness that plays no causal role. If imagery confers an advantage on concrete words, then interfering with the image, either at encoding or at retrieval, will reduce the number of concrete words that can be recalled. This prediction has been tested, and confirmed, in a number of studies of paired-associate learning, which are reviewed next.

Paired-associate learning. Atwood (1971) was the first to employ the interference paradigm to obtain evidence for the role of imagery in verbal learning. In this study, subjects learned paired-associates embedded in short phrases. High imagery words appearing in phrases such as "nudist devouring a bird" and "pistol hanging from a chain" were learned by visualizing the described scene. Low imagery words in phrases such as "the theory of Freud is nonsense" were learned

by considering the meaning of the statement. In the interference conditions, interpolated between successive word pairs the numbers "1" or "2" were either visually or auditorily presented and subjects responded by naming the digit not presented. Atwood found that, for the imaginal phrases, recall scores were lower when the digits were visually presented than when they were auditorily presented. With abstract paired-associates, however, recall scores were higher when the digits were visually presented.

Though widely cited, Atwood's experiment has been criticized as methodologically flawed for reasons that include the confounding of concreteness with instructions to use imagery (Baddeley, Grant, Wight, & Thomson, 1975; Clayton & Warren, 1976; Janssen, 1976 b). Nevertheless, Janssen (1976 a Experiments I & II; 1976 b), using a more appropriate design, replicated the finding that recognition of visually presented digits during the acquisition phase interferes with recall of noun pairs. In that study, interference effects were predicted only by concreteness, irrespective of whether the mediational strategy was imaginal or verbal. Interference effects were also independent of imagery ability, defined by performance on Bett's Questionnaire Upon Mental Imagery. In a subsequent study using the same interfering task, Janssen (1976 a Experiment IV;1976 c) demonstrated that recall of high imagery noun pairs could also be disrupted at retrieval. In that study, an interaction between interfering task and learning strategy was also found, in contrast to the results of Janssen's earlier findings.

Logie (1986) also reports interference effects as a function of mediational strategy. In particular having subjects respond to successive identical visual patterns produced a substantial decrement in recall of concrete words learned using the pegword mnemonic but had no effect on rote learning. Words learned using the

pegword mnemonic were also differentially affected by unattended stimuli including matrix patterns, line drawings, and colored squares.

Though it has been argued that representing the spatial "layout" of the imaged objects is critical in remembering paired-associates (Kerr and Neisser, 1983), interference studies provide only weak support for this conclusion. If the spatial relationship between the imaged objects, and not the visual detail of the images, were important, then memory for paired associates should be most vulnerable to a spatial interfering task.

Bower (1972) reports that learning concrete paired-associates by interactive imagery is disrupted more by visual tracking than by tactile tracking, while both tracking tasks have comparable effects on rote learning. Yet this does not constitute evidence for a spatial component in paired-associate learning, because although the interfering tasks are both spatial, they *differ* primarily in modality.

It is possible, however, that interactive imagery places the imaged objects in a spatial relationship, and in this way renders them susceptible to spatial interference. In considering the relative contributions of the object and spatial systems in imaging paired-associates, findings regarding the pegword mnemonic are pertinent because the type of images constructed seem, intuitively, to be indistinguishable from those of paired-associates. It is therefore necessary to account for Baddeley and Lieberman's (1980) finding that tracking during presentation and recall interferes more with memory for both concrete and abstract words learned using the pegword mnemonic than with rote rehearsal. This result suggests that there is a spatial component in interactive imagery.

If the interaction between imaged objects is the source of the conflict produced by tracking, however, then tracking should not interfere with noun-

adjective paired-associates since these can be imagined as a single object having the attribute denoted by the adjective. Consistent with this prediction, tracking during presentation and recall of imageable noun-adjective paired-associates, e.g. strawberry-ripe, bullet-gray, table-square etc., did not impair memory compared to abstract, noun-adjective pairs such as gratitude-infinite (Baddeley, Grant, Wight, & Thomson 1975).

Taken together, the results of Baddeley and Lieberman (1980) and Baddeley et al. (1975), seem to converge on the interpretation that memory for noun paired-associates entails a spatial component because the objects are imaged in a particular spatial relationship. Before accepting this conclusion, however, it is necessary to consider the following alternative explanation of these results: The comparison memory task used by Baddeley and Lieberman (1980) was rote learning, while the comparison task used by Baddeley et al. (1975) was recall of abstract noun-adjective pairs. As the determination of selective interference is always relative to a comparison task, the possibility exists that the difference in results lies not in the effects of tracking on the imagery tasks but in the effects of tracking on the comparison tasks.

In fact, this appears to be the case: Compared to a no-interference control condition, the decrement in recall produced by tracking compared to a no-interference condition is roughly 10% for words learned using the pegword technique and for both concrete and abstract noun-adjective paired-associates. Only rote learning is unaffected by tracking. Although Baddeley doesn't explicitly view it in this way, comparing across studies, it appears that tracking affects interactive images and images of single objects to the same extent, but has no effect on rote learning. This in turn raises the possibility that the effects of tracking are predicted

simply by the amount of cognitive effort required. To rule out this interpretation, Baddeley and Lieberman (1980) compared the effects of tracking on rote learning and on a verbal mnemonic. In contrast to the selective effect of tracking on the pegword mnemonic, the verbal mnemonic was no more disrupted than rote learning. This suggests that the interference of tracking on the pegword mnemonic is not attributable simply to general difficulty. Nevertheless, the use of a second interfering task would permit a clearer interpretation of the effects of tracking of interactive imagery.

The strongest evidence on the relative contributions of object and spatial imagery in recall of high imagery paired-associates comes from a study in which subjects learned a mixed list of high and low imagery nouns using either an imagery strategy or a verbal strategy (Janssen 1976a Experiment V). Three interfering tasks were used: These were auditory or visual presentation of digits with no response required, or a type of "tracking" task in which subjects traced jagged lines with a pencil. The earlier finding of an interaction between modality of digit presentation and imageability was replicated: Visually presented digits were more disruptive than auditorily presented digits to the recall of high imagery words, while the reverse pattern was obtained with low imagery words. However, the spatial interfering task, while significantly more difficult than the nonspatial interfering tasks, did not selectively impair recall of high imagery words.

To summarize, the tasks that interfere with recall of paired-associates implicate the object imagery system in interactive imagery. These results suggest that in contrast to a strategy such as the method of loci in which the salience of the spatial location of each item is critical, the role of spatial imagery in remembering paired-associates is minimal. Instead, *unity*, is probably the more important factor

(cf. Begg, 1978). Though two objects are imaged, in some sense they are represented as one; the role of the spatial imagery system is therefore minimal.

Memory for concrete words. There are few studies that compare the effects of an interfering task on concrete and abstract words. Matthew's (1983) compared the effects of verbal and nonverbal memory tasks on recall of high versus low imagery words, however since the visual processing demands of the two conditions were nearly identical, the findings are not particularly informative for the purposes of this thesis.

The only evidence on interfering with memory for individual concrete words comes from Janssen (1976a Experiment III), who used the interfering digit task developed by Atwood to demonstrate an interaction between modality and imageability of single nouns. This effect did not vary either with imagery ability, as measured by Betts' Questionnaire or with mediational strategy. The latter effect suggests that images are formed even when subjects are not specifically instructed to use imagery. Consistent with this result, Farah, Weisberg, Monheit and Peronnet (1989) found that when concrete words are read, the amplitude of an event-related potential (ERP) component thought to index image formation is intermediate between that which occurs when subjects read the words and image their referents and that which occurs when abstract words are read. These findings are consistent with Janssen's results insofar as they support the notion that subjects generate images to concrete words even when they are not explicitly instructed to do so. It is not clear from the Farah et al. study that imagery contributes to the memorability of concrete words, however, since no recall measure was obtained.

As there is only one experiment that shows interference of individual concrete words, but many that show interference of paired-associate learning, it

may be that imagery contributes less to memory for concrete words than it does to paired-associate learning. Baddeley et al. (1975) propose a distinction between concreteness as a "semantic feature" and imagery as a strategy. If this explanation is extended by assuming that imagery is used as a strategy for learning concrete paired-associates even in the absence of explicit instructions to use imagery, it may explain the abundance of interference effects with paired-associates and the relative lack of published studies using individual concrete words. In other words, semantic factors may be largely responsible for concreteness effects, while object imagery plays a more critical role in paired-associate learning.

Evidence that tracking during recall fails to interfere with memory for concrete words (Warren, 1977) is consistent with the position that interference will only occur when the imagery and perceptual tasks tax the same neural system (cf., Janssen, 1976 a). On this account, memory for concrete words is unaffected by tracking because images of concrete words are generated within the object system, while tracking, which requires continuously monitoring the movement of a very simple target, relies primarily on the spatial system. The two tasks, though visual, involve separate systems, and can therefore be carried out simultaneously with minimal conflict. However the finding that tracking has no effect on recall of concrete words is equally consistent with the view that concreteness effects have a semantic basis.

Memory for pictures. In support of semantic interpretations of concreteness, tracking during recall is significantly more detrimental to memory for line drawings than to memory for the corresponding verbal labels (Warren, 1977). On the other hand, this finding is not predicted by the object/spatial distinction. However, a more appropriate test of the spatial component in picture recall would include a second

interfering task. Such a study was conducted by Byrne (1974). To anticipate the conclusions of that study, Byrne demonstrated that a spatial interfering task is no more disruptive to memory for pictures than a verbal task.

Byrne's (1974) experiments are particularly informative in supporting the existence of separate object and spatial imagery subsystems since Byrne was sensitive to a similar distinction. Specifically, he observed that:

> ... there seems to be a distinction between generating images of things... and engaging in a spatial search, or directional activity... that links the more static images. (p. 53)

In the first experiment, Byrne (1974) explored the relationship between spatial organization and concreteness by having subjects classify items from memory using verbal or spatial response modes. Subjects learned a list of ten words whose referents could be organized as a coherent picture of a farm. The words were either read to subjects, or read as the experimenter pointed to each item in the picture. After learning the items to criterion, subjects categorized them from memory either verbally or by pointing to Y's and N's on a response sheet. Subjects responded "yes" to animals or, alternatively, "yes" to items classified as man-made. Byrne found that, for subjects who had not seen the picture, pointing and verbal response times were virtually identical. In contrast, subjects who had been shown the pictorial scene were slower to respond by pointing. Since pictures are more likely than words to be nonverbally coded, however, subjects who only listened to the words may not have used imagery to aid recall. In the second experiment, however, pictures of the individual items were individually presented. When the spatial organization was omitted in this experiment, verbal responses took as long as pointing.

Subsequent experiments conducted by Byrne indicate that a response mode

difference also occurs when subjects are simply read a list of related words and instructed to form their own mental scene, and even when subjects are given no explicit instructions but learn a list of words that have an inherent spatial organization, e.g., lawn, carpet, roof etc..

The independence of object imagery and spatial organization demonstrated by Byrne is ultimately a reflection of the division between object and spatial imagery, and further supports the claim that imagining individual objects is distinct from the processing that occurs when relationships between separately stored representations are made salient.

In this section, studies of interference of object imagery including memory for patterns, letters, pictures of individual objects, concrete words, and imageable paired-associates, have been reviewed. For the most part, the tasks that have been demonstrated to disrupt object imagery involve presentation of patterns, line drawings, and single digits and letters. Responses to these tasks, if elicited, have been verbal, and there is no clear case in which processing in another modality has proven more disruptive than a verbal task. The next section describes the conditions under which spatial imagery is disrupted.

Interfering With Spatial Imagery

This section describes a variety of experiments on interference of spatial imagery. Two imagery tasks devised by Lee Brooks have been used repeatedly in the interference paradigm, and evidence concerning these is reviewed first. Following this, several other interference studies of spatial imagery are considered.

Brooks' letter corner task

In Brooks' (1968) classic interference experiment, subjects were given verbal or nonverbal material to be memorized, and then instructed to classify the

information held in memory. In the imagery condition, subjects formed an image of a block letter and beginning at a designated spot, classified each letter corner in turn either by responding "yes" to corners at the extreme top and bottom of the letter or, alternatively, at the extreme right and left of the letter, and "no" otherwise. In the verbal memory condition, subjects listened to a sentence and then classified each word from memory by responding "yes" to nouns, or to grammatical articles, and "no" otherwise. For both verbal and imagery tasks, subjects responded either verbally, or by pointing to Y's and N's in an array, or by tapping with the right versus the left hand.

Brooks found that when subjects were classifying letter corners, pointing responses were slower than verbal responses. Conversely, when classifying words in a sentence, verbal responses were slower than pointing responses. The difference between tapping and vocal responses in the imagery condition approached significance, and may have provided an early indication of the nonvisual spatial component in Brooks' task, but this result is generally dismissed and the interference characterized as modality specific. Brooks himself described the interference in these terms, yet he did not imply that the interference was specific to the visual modality. Subsequent experiments using the letter corner task, which will be described next, lead Brooks to conclude that the interference he observed also involves a nonvisual spatial component. Though he continued to refer to the interference effects as modality specific he qualified his terminology by noting that:

> A problem... arises in attempts to define the boundaries of a "modality". The boundaries of such a hypothetical system obviously cannot be identified with any traditional sensory or motor system... both tactual and visual or kinaesthetic monitoring conflict with the same type of recall. (p. 367)

It now seems apparent that the "modality" Brooks described, that extends beyond one sensory system to include tactual, visual, and kinesthetic information is the spatial "modality", subserved by the posterior parietal cortex. Consistent with this interpretation, Farah, Hammond, Levine, and Calvanio (1985) tested a patient with occipital-temporal damage on Brooks' letter corner task and found that, in contrast to his poor performance on a variety of object imagery tasks, he performed as well as normal control subjects on the letter task. This may suggest that the letter corner task does not rely heavily on the object imagery system (but also see Goldenberg et al. (1989) for evidence that this task activates occipital and inferior temporal cortex).

Other experiments Brooks (1968) conducted indicate a spatial component in the letter corner task by demonstrating interference by a nonvisual task. One follow-up experiment explored the interfering effects of visually guided and unguided arm movements by pairing the letter corner and sentence tasks with three different types of written responses: Checks and X's, denoting positive and negative responses, were made either all in the same place (no-movement), each below the previous one without looking at the response sheet (unmonitored movement), or in boxes of a vertical column (monitored-movement). Brooks found no differences among these conditions when subjects were classifying words from a memorized sentence. In contrast, when subjects were classifying corners of a letter, responses made by visually guided movements were slowest, and unmonitored movements produced more interference than responses not requiring movement. The comparison between visually guided movements and nonvisually guided movements may indicate that some component of the interference is specifically visual. Alternatively, greater spatial precision may be required when responses are made in specific locations

(boxes). Of particular importance, the comparison between nonvisually guided movements and no-movement responses indicates that not all of the interference produced by visually guided pointing is attributable to perceptual processing, but that executing the response contributes to the observed interference as well.

A subsequent experiment confirmed the somatic, and hence spatial, contribution to interference. In this study, subjects again classified the letter corners and words by writing checks and X's. Unmonitored movement responses were compared with tactually monitored movement in which subjects located holes in a piece of cardboard through manual exploration and then wrote their responses in these holes. Although tactually guided movements produced more interference than unmonitored movement with both memory tasks, there was a differential slowing in the imagery condition.

Additional evidence of the spatial component in Brooks' letter corner task is that tracking accuracy is lower when subjects are simultaneously classifying letter corners than when they are classifying words in a sentence (Baddeley, Grant, Wight, & Thomson, 1975).

The findings of these experiments, and others to be reviewed in a later section, demonstrate that spatial imagery may be disrupted by both visual and somatosensory processing. These findings constitute some of the most compelling evidence that the posterior parietal cortex plays a role in imagery, for they suggest that spatial imagery recruits neural mechanisms in which there is a convergence of visual and somatosensory information.

Brooks' matrix task

Another set of verbal and nonverbal memory tasks devised by Brooks' (1967) have also been used repeatedly in interference studies of imagery. These

tasks examine recall of spatial and nonspatial adjectives presented in short phrases that in the spatial condition can be mapped as a path on an imaged matrix. The spatial adjectives- right, left, up, and down, are presented in a format that reads, for example, "In the starting square put a 1. In the next square to the left put a 2. In the next square up put a 3", and so on to describe the placement of the digits 1-8. In the verbal memory condition, the nonspatial adjectives quick, slow, good, and bad are substituted into the same messages to create a "nonsense" sequence. As in the imagery task, the messages begin "In the starting square put a 1" but then proceed, for example, "In the next square to the good put a 2. In the next square to the quick put a 3", etc. In both conditions, subjects listen to one sequence and then repeat the message verbatim.

Brooks' (1967) found that reading the messages as they were auditorily presented increased the number of errors in the spatial condition compared to just listening to the messages. Conversely, however, reading and listening decreased the errors in the nonspatial condition. In another experiment, recall of the spatial sequences was differentially disrupted at retrieval, as reflected in time to complete the task, when subjects responded by underlining the key words in a multiple choice test format rather than by saying them. A consideration of the object and spatial components in these imagery and perceptual tasks suggests that the interference occurs within the spatial system. Reading is assumed to involve spatial processing because unless the words are presented one at a time in the same location, reading requires systematic shifts of attention. This assessment of the spatial component in reading is strengthened by reports that reading difficulties may follow injury to the parietal cortex (Hyvarinen, 1982; Critchley, 1953). In their description of a patient with damage to this region, Levine, Warach, and Farah (1985) observed that

> In reading, he... could read a few isolated words of a paragraph, but in no particular order, jumping from one line to another or from one location in a line to another. (p. 1014)

Other interference studies also demonstrate a spatial imagery component in Brooks' matrix task. For example, pursuit rotor tracking differentially increases the number of errors in recalling the spatial sequences (Baddeley, Grant, Wight, and Thomson, 1975). Baddeley and Lieberman (1980) more precisely characterized the source of the interference between Brooks' matrix task and tracking by comparing the effects of a nonvisual spatial interference task and a nonspatial visual interference task on memory for spatial and nonspatial adjectives. In the spatial interfering task blindfolded subjects tracked a pendulum using auditory feedback: When a flashlight beam was shone on the pendulum a series of beeps sounded, if the light was not hitting the target the beep changed to a constant tone. Auditory tracking during encoding and retrieval disrupted recall of the spatial, but not the nonspatial, adjectives.

Having demonstrated that a nonvisual spatial task interferes with memory for the spatial sequences, Baddeley and Lieberman next examined the effects of a nonspatial visual task. In this interfering task bright and dim patches of light were presented, and subjects pressed a key whenever a bright stimulus appeared. In contrast to the effects of auditory tracking, judging brightness interfered only with memory for the nonspatial messages. Recall of the spatial sequences in the interference condition did not differ from that of a no-interference control condition. From the results of these two experiments, the authors conclude that the images that mediate Brooks' matrix task are spatial rather than visual. The exact source of the interference is left unspecified, however it seems likely that the interference arises from both the spatial sensory input (cf. Smyth & Scholey, 1994) and the spatial

response mode.

A conceptual replication of the effect reported by Baddeley and Lieberman is documented by Quinn (1988), who compared the effects of tactile tracking and judging brightness on memory for spatial and nonspatial adjectives. In the tactile tracking condition, subjects depressed individual keys on a 5 x 4 array in a specified sequence. The array was covered so that the subject could see neither the array nor his hand. Consistent with the findings of Baddeley and Lieberman (1980), Quinn (1988) found that tactile tracking was more disruptive to memory for spatial adjectives than judging brightness, while the two perceptual tasks were equally disruptive to memory for nonspatial sequences. On the other hand, Beech (1984) reports that tactile tracking and judging brightness are both disruptive to recall of spatial adjectives, while neither disrupts recall of nonspatial adjectives. He concludes that the matrix task involves both a visual (object) component and a spatial component.

Quinn and Ralston (1986) extended the findings regarding the interference produced by arm movements by showing that recall is only affected when the movements conflict with the directions given in the spatial sequences. They also determined that incompatible arm movements interfere with encoding the spatial sequences even when the subject's arm is moved by the experimenter. Since passive responses do not require planning or execution, this finding suggests that kinesthetic information alone is sufficient to disrupt spatial imagery.

Once it is assumed that the posterior parietal region plays a role in spatial memory, the disruption of recall for spatial material by manual tracking is readily understood by reference to evidence that some neurons in this area are "ambiguous" with respect to modality. Since those neurons serve to establish a correspondence

between visual input and motor output, it is not surprising that a discrepancy between spatial imagery and motor responding should prove disruptive.

Yet although the available evidence points to the role of spatial imagery in Brooks' matrix task, it could be argued that an appropriate test of the object component has not been made. This is because the "visual" task of judging brightness may not be an ideal task for selectively engaging the object system: Livingstone and Hubel argue that the magnocellular division of the visual system relies primarily on brightness contrast to extract information about depth and motion. A pattern perception task would be more informative for evaluating the contribution of object imagery to Brooks' matrix task. Yet given the number of different studies that have used this imagery task, the abundance of evidence for the role of the spatial system and the lack of evidence for the role of the object system, it seems plausible that the imagery is primarily spatial, with only a minimal role of the object system.

In summary, a large number of studies converge on the interpretation that Brooks' tasks primarily require spatial imagery: Brooks' letter corner task is interfered with by pointing to visual targets, by tracking, and by nonvisually guided movement. Brooks matrix task is disrupted by reading, and by a variety of tracking tasks including visual tracking, tracking on the basis of auditory feedback, and tactile tracking. The interfering tasks that have proven disruptive to the matrix and letter corner tasks have been paired with a variety of other imagery tasks as well. Not surprisingly these imagery tasks generally seem to have a spatial component.

Other spatial imagery tasks

Brooks (1970) demonstrated an interfering effect of reading on imaging objects in specific spatial relationships. The type of description subjects were asked

to imagine was, for example, " The goat is to the left of the rock and above the fountain". After it was established that subjects had the image in mind, they then either listened to the description again, listened to the description and read it, or listened to the description and saw a picture in which the object labels were placed in the appropriate relative locations. Subjects were then instructed either to simply repeat the original description, or to rotate the array 90 degrees clockwise or counterclockwise and describe the placement of the objects. Brooks found that subjects repeated the original description more quickly after having read it. When they had to rotate the image, however, response times were longer when subjects read the description. Latencies to respond after viewing the corresponding picture were no longer than those associated with simply listening to the description.

Further evidence for interference between reading and imagery is provided by Arnold Glass and his collaborators (e.g., Eddy & Glass, 1981; Glass, Millen, Beck and Eddy, 1985). The sentence verification paradigm used in these studies to investigate the nature and role of imagery in sentence comprehension is adapted in Experiment 2 to separate object and spatial components. A discussion of these findings is therefore postponed until Chapter 3.

The remaining studies to be considered in this section have paired a variety of imagery tasks with arm movements. Before considering these, however, there is one study by Johnson (1982) in which memory for arm movements served as the imagery task. To anticipate, his findings are based on a comparison between two secondary tasks, which in theory limits the validity of his results if the two tasks are not of comparable difficulty. Nevertheless, it would be difficult to argue that the task that produced greater interference is generally more difficult since it involved only looking at a stimulus and required no response.

The experiment began with a series of acquisition trials in which subjects practiced moving a block along a track to a marked position. The marker was then removed and subjects reproduced the movement from memory. Johnson first demonstrated that having subjects imagine moving to a different location in the retention interval produced a bias in memory for the original movement. Of particular interest, however, is what happened when a second task was added to the retention interval: Having subjects watch a display of two oscillating waves removed the bias in performance typically caused by imaging a novel movement. By comparison, having subjects squeeze a dynamometer to a constant pressure had no effect. Johnson's finding supports the notion that memory for movement (or distance) is disrupted by visual processing of movement.

Secondary tasks involving arm movements also interfere with certain types of reasoning tasks. For example, in a study by Farmer, Berman, and Fletcher (1986) having subjects tap on four plates in a clockwise pattern interfered with spatial reasoning, but had no effect on verbal reasoning. In the verbal reasoning task, a pair of letters was displayed and subjects determined whether a statement describing the order of the letter was or was not accurate. In the spatial reasoning problem, subjects were shown a mannequin figure holding a circle in one hand and a square in the other. The figure was shown from either a front or rear view and either upright or upside down. A probe shape was then presented and the subject verbally indicated whether that shape was held in the left or right hand.The tapping task did not affect the verbal reasoning problems but increased reaction times for the spatial reasoning task when the figure was inverted. The interference was even greater when the figure was inverted and the rear view presented, which suggests that subjects rotate the figure prior to making the left/right determination and that it

is this process that conflicts with the tapping task. It could be argued that the increased interference in the inverted and rear view conditions occurs because the trials requiring mental rotation are generally more difficult, however another experiment demonstrated that articulatory suppression did not interact with these factors. It therefore seems likely that the interference reflects a shared processing substrate. This interpretation is strengthened by numerous studies indicating that the posterior parietal lobe functions in some aspect of mental rotation (Stuss, et al., 1983; Peronnet & Farah, 1989; Butters et al., 1972).

Tactile tracking also interferes with some types of problems concerning temporal order, as shown in Friedman's (1983) study. Friedman compared two types of questions concerning the order of the months. In the first type of problem subjects were asked to determine which of two months is closer, going backwards in time, to a reference month, e.g., is June or May closer to September. In the second type of problem, subjects were asked to name the month which comes 2, 3, or 4 months after the reference month. Subjects were not instructed to use a particular strategy, but Friedman assumes that they use the optimal strategy, which for the "backwards" task is to use imagery and for the "forwards" task is to covertly recite the names of the months. When both types of problems were paired with tactile tracking it was determined that responses to "forwards" questions were faster when paired with tracking, while responses to the "backwards" questions were slower when paired with tracking. Friedman's finding is particularly interesting because it suggests that temporal information may be represented spatially and rendered susceptible to an interfering task such as tracking.

A recent study by Smyth and Scholey (1994) is especially informative in clarifying the nature of the interference that occurs within the spatial system. These

authors paired a spatial memory span task with a variety of interference tasks. In the spatial span task, an array of nine square targets appeared on a computer screen. On each trial, a subset of the targets turned black one at a time. Following a short delay, subjects recalled the sequence by touching the targets in the correct order. Various types of tasks were performed during the retention interval.

In one experiment, a series of 6 visual or auditory targets was presented during the retention interval. The visual targets were squares presented in one of two locations on the computer screen. The auditory targets were tones emitted from either of two spatially separated speakers. The modality of the interfering task varied between subjects. Within each of these two groups, subjects participated in a no-interference (unfilled) condition, and three interference conditions that varied only in the nature of the required response. These latter three conditions required 1) no response, 2) a pointing response to each target as it was presented or 3) a verbal response indicating whether the target was on the "right" or "left".

Smyth and Scholey found no effect of modality, nor did modality interact with interference task. For both auditory and visual targets, the verbal and pointing responses produced the same amount of interference, which was significantly greater than the no response condition. The no response condition also produced greater disruption than the unfilled interval. In comparison, listening and pointing to tones had no effect on digit span.

These results demonstrate that processing in another modality can interfere with spatial memory. They are also particularly important in suggesting, as the authors point out, that the interference arises from competition for spatial attention. Extrapolating from their results, and considering the variety of tasks that interfere with spatial imagery i.e., reading, tracking in any modality, watching a moving

target, and making arm movements, it seems likely that indeed the source of conflict is in spatial attention.

Studies That Address The Object/Spatial Distinction

An appropriate test of the hypothesis that an imagery and perceptual task will be mutually disruptive to the extent that they rely on either the object or spatial system requires pairing object and spatial imagery tasks with object and spatial perceptual tasks and demonstrating an interaction between these factors. Two recent studies described below, and the first experiment in this thesis, provide direct tests of the hypothesis using such a design.

In a study conducted by Logie and Marchetti (1991), subjects were required to remember either four shades of a single color or the sequence in which 6 squares were shown for a later recognition test. In the interference conditions, subjects performed one of two tasks during the retention interval. They either viewed five line drawings under instructions to ignore them or depressed the buttons on a 5 X 5 matrix in sequential order. The latter task was spatial but nonvisual by virtue of the fact that the matrix was covered by a box, with a flap at one end through which the subject moved his am. Logie and Marchetti found that recognition of the spatial sequences was unaffected by presentation of line drawings but decreased as a result of the arm movements. Conversely, color recognition was disrupted only by viewing the line drawings.

Tresch, Sinnamon, and Seamon (1993) also demonstrated an interaction between memory and interference task. In contrast to Logie and Marchetti, who frame their research in terms of the Working Memory model (Baddeley & Hitch, 1974), Tresch et al. present their study in terms of object and spatial systems with separate anatomical underpinnings. Their rationale, presented below, is strikingly

similar to that presented in this thesis:

> Interference should occur when primary and secondary tasks make simultaneous and significant demands on the same processing system. A spatial processing primary task as reflected in memory of location, might be selectively impaired by a movement discrimination secondary task because both tasks rely on posterior parietal areas. In the analogous case, a visual object primary task, as reflected in memory of object form, might be selectively impaired by a color discrimination task because both tasks rely on inferotemporal cortical areas. (p 212)

Subjects in this study were asked to remember either one of eight geometric forms or the position of a dot. During the retention interval, subjects performed either no task (unfilled condition), a movement discrimination task or a color discrimination task. In the movement discrimination task, subjects viewed a screen containing a stationary target amidst moving distractors, and identified the target by moving the cursor to it. In the color discrimination task, subjects were shown monochromatic displays and classified each as a member of either the red or blue family. In all three conditions, an articulatory suppression task was also used to increase reliance on visual memory.

As the authors predicted, memory for location was disrupted more by movement discrimination than by the color task, while memory for geometric forms was disrupted more by color discrimination than by the movement task.

It is noteworthy that the two published studies that have used selective interference to provide evidence for object and spatial imagery subsystems have used color as an object task, and that neither has demonstrated that images of objects are selectively disrupted by pattern perception. This is somewhat surprising given that the latter combination of interference and memory tasks bear a stronger surface similarity. Moreover, the pathway for color vision is separate from that for form vision at the level of the primary visual cortex (Livingstone & Hubel, 1987), a

region that has been implicated in mental imagery (Kosslyn, Alpert, Thompson, Maljkovic, Weise, Chabris, Hamilton, Rauch, & Buonanno, 1993). It should therefore be possible to demonstrate the existence of object and spatial imagery systems using object imagery and perception tasks that involve memory for form and pattern perception, respectively. Experiment 1 addresses this possibility.

Experiment 1

This experiment compares the effects of spatial and object perceptual tasks on memory for descriptions of spatially arranged objects. In contrast to the two studies described above that used separate object and spatial imagery tasks, the present study uses stimuli that incorporate both object and spatial components. The use of composite stimuli has successfully been used to dissociate imagery and verbal memory (den Heyer & Barrett, 1971; Allen, Marcel, & Anderson, 1978). In these studies subjects were shown letters in a matrix and asked to remember both the items and their locations. It was then shown that different tasks, performed during the retention interval, could selectively impair recall of one of these stimulus dimensions. Experiment 1 is an attempt to selectively disrupt recall of the items or of the spatial relations according to the nature of the interfering task performed as the stimuli are encoded. An interaction between the perceptual tasks and the two components of the memory task would indicate a separation of the object and spatial systems in mental imagery.

Method

Subjects. Sixteen Duke undergraduates served as subjects. They participated for credit in an undergraduate psychology course.

Stimuli and apparatus. On each trial, subjects listened to a description of a group of spatially arranged objects: Each consisted of 6 sentences describing an array of 6 objects. A sample description follows.

> There is a desk
> The cup is above the desk
> The swing is to the left of the cup
> The bed is above the swing
> The violin is to the left of the bed
> The harp is to the left of the violin.

These stimuli were modeled after the "referentially continuous" descriptions used

by Oakhill and Johnson-Laird (1984) in which each sentence refers to an item mentioned in the preceding sentence. Oakhill and Johnson-Laird found that having subjects track a moving target interfered with their ability to recall such descriptions, and interpret this result as evidence for a "visuospatial" encoding of these stimuli. Moreover, tracking increased omissions of the relations between objects but did not increase omissions of the objects themselves. The finding of selective interference of the spatial relations by tracking made these descriptions a good candidate for material that comprise separable object and spatial components. Although the objects could conceivably be remembered either by constructing images of the objects or by remembering the item names, subjects in this experiment were explicitly instructed to represent the items using imagery.

Two sets of 10 descriptions were created in the following manner. First, 10 different spatial layouts were constructed. These determined how the 6 objects in each description would be arranged. For the sample description given above, the spatial layout can be graphically depicted in the following manner:

```
6 -- 5 -- 4
          |
          3 -- 2
               |
               1
```

A second set of layouts was created by rotating each of these ten layouts 90 degrees. Rotations of the first set were used to try to equate the complexity of the spatial layouts for the two sets. Next 120 object names were selected from the Snodgrass and Vanderwart (1980) corpus, and randomly assigned a location in one of 20 spatial layouts. A few (approximately 4) items requiring the plural "are" instead of "is" were assigned the first location. In addition, to maintain consistency in the wording of the descriptions "pliers", "scissors", and "glasses" are described

as "a pair of...", e.g., "a pair of pliers", in the first line of the description. In the second line the item is referred to simply by the one word name. Descriptions were tape recorded with Psychlab controlling the timing of sentence presentation. Sentences were presented at approximately a 7.5 second rate. The 20 stimulus descriptions are presented in Appendix B.

Design and Procedure. Subjects were tested individually. They were instructed to listen to the descriptions and to try to remember them for a later recall test by forming an image of the array. Recall was assessed by having subjects draw the diagrams of the layouts using words to denote the objects. They were told to recall the descriptions in serial order. A correct recall protocol for the sample description given above is shown here:

harp -- violin -- bed
|
swing -- cup
|
1 desk

Subjects were instructed to place an "X" at any location in which they are unable to recall the object, and to put a "1" by the first object.

As the subject listened to the descriptions they performed one of two interfering tasks. Selection of the interfering tasks was based on a consideration of the types of tasks that have successfully been used in prior research. All subjects served in the following two interference conditions.

1) *Visual Tracking*. Tracking was selected as the spatial perceptual task because tracking is reported to selectively disrupt recall of spatial sequences (Baddeley, Grant, Wight, & Thomson, 1975) but not recall of high imagery words (Baddeley, et al. 1975; Warren, 1977; but also see Baddeley & Lieberman, 1980). In this experiment, subjects used a mouse to track a moving target on the computer

screen. The target moved back and forth in a sinusoidal path across the screen. Time on target was recorded.

2) *Letter Identification.* The letter identification task was designed to be conceptually similar to the visual interference tasks reported by Atwood (1971) and Janssen (1976) to interfere with recall of high imagery verbal material. In those studies, subjects saw one of two digits and responded by naming the digit not presented. In this experiment the complexity of the visual display was increased in an attempt to increase the amount of interference. This was accomplished by using arrays in which the screen was filled with symbols of a single type, e.g., all "A"'s. The display changed at a rate of once per second.

Subjects sat in front of the computer monitor with their hands positioned on the space bar, and were instructed to press the space bar whenever the symbol from which the array was constructed was a letter. Subjects were informed that each display would be constructed from only one type of symbol and that they could therefore base their response on any individual symbol in the display. This instruction was included to discourage subjects from scanning the display, which might introduce an unwanted spatial component to the task.

The stimulus displays and collection of responses for both interfering tasks were controlled by programs designed for an IBM compatible 286 computer with an EGA monitor.

On each trial, a tone occurring approximately 7.5 seconds prior to the onset of the stimulus description served as a signal to begin the interfering task. Each interfering task was timed so that its duration was equal to the interval between the first tone and a second tone that followed the last sentence of the description. Upon hearing this second tone subjects recalled the description. The recall period was 30

seconds. At this time, a "ready" prompt indicated that the recall period had ended and the next trial was about to begin. The tone then signaled commencement of the next trial.

Prior to the test trials subjects listened to a sample description as they looked at a drawing of the array. They were then given 2 practice trials in which they performed only the recall task. For these first 2 practice trials they were shown a corresponding picture as they listened to the verbal description. Following these two practice trials they were informed that during the remainder of the experiment they would not be shown pictures and should therefore use imagery to help them remember the material. They were then introduced to the interference tasks, given practice on each of the interference tasks alone, and then given 2 practice trials with each of the interfering tasks. Instructions emphasized the need to maintain accuracy on the interfering tasks.

Subjects completed ten trials in one interference condition and then ten trials in the alternate condition. Half of the subjects performed the letter judgment task followed by the tracking task and half performed the tracking task followed by the letter judgment task. The order of stimulus sets was counterbalanced.

Results

Mean time on target in the tracking task was 14.75 seconds. The mean number of errors on the letter judgment task was 4.18.

Following Oakhill and Johnson-Laird each recall protocol was scored for both the number of correct items (of 6) and the number of correct spatial relations (of 5). The spatial relations were scored according to whether each marked location was in the correct position relative to the immediately preceding location. Scores were converted to percentages to permit direct comparison between these two

scores.

A 2 X 2 within-subjects MANOVA was performed on the mean percentages of items and spatial relations correctly recalled. This analysis indicated main effects for both the imagery and perceptual tasks. Specifically, subjects recalled a higher percentage of items ($M=81\%$) than spatial relations ($M=72\%$), $F(1,15)=6.68$, $p < .05$. Recall was also better when subjects tracked ($M=80\%$) than when they judged letters ($M=73\%$), $F\ 1(1,15)= 10.88$, $p < .005$. Although the interaction of these two factors borders on significance, $F(1,15)= 3.63$, $p =.08$, inspection of the means shows this to result from a trend other than that predicted. Although both the objects and spatial relations are remembered less well when subjects judge letters than when they track a moving target, this decrement is more pronounced for the spatial relations. The means are shown in Table 1.

Table 1

Mean Percentage Recall and Standard Deviations (in Parenthesis) for Objects and Spatial Relations as a Function of Interference Task

	Interference Task	
	Tracking	Judging Letters
Objects	83.44 (10.77)	78.23 (12.28)
Spatial relationships	76.63 (15.44)	67.00 (17.10)

Discussion

One possible explanation for the failure to detect selective interference in Experiment 1 is, that since the interfering tasks are performed at the time of

encoding, subjects may be able to direct additional resources to the task of remembering the affected component. Although the possibility of using an interpolated task was considered, it has been suggested that some types of material are encoded and retrieved using the spatial system, but maintained as a "static pattern" (Logie & Marchetti, 1991). For example Quinn (1991) found that arm movements made during presentation of the Brooks' matrix sentences interfered with subsequent recall of the material, while arm movements made during the retention interval did not. In his discussion of the differential effects of concurrent and delayed arm movements, Quinn speculates that "...once formed the directions are remembered as an overall pattern rather than a sequence of discrete relative directions..." (p. 103). In light of these findings, it was decided to have subjects perform the interfering tasks at encoding rather than use an interpolated task.

A second potential explanation for the failure to find an effect in the present study is suggested by Tresch et al. (1993), who preface their study by anticipating that demonstrating a behavioral dissociation between the object and spatial systems may be difficult because the two pathways are not entirely segregated. Although there are now two studies that have demonstrated such a dissociation both of these have used color as an object task. Might the use of color facilitate the behavioral dissociation?

A recent review by Zeki (1993) of the structure of the visual pathways suggests a reason why this might be the case. Zeki argues that the notion of two, and only two, independent pathways is an oversimplification. He claims that there are not two, but four pathways, and that these are not isolated, but highly interconnected. Zeki maintains that there are four systems devoted to analysis of 1) motion 2) dynamic form 3) color and 4) form in association with color. Two points

are worthy of consideration here. First, that although form and color are segregated in the primary visual cortex and in area V2, most of the cells in area V4 that are orientation selective are also wavelength selective. Therefore, in the higher visual areas, the same cells represent both form and color. Second, Zeki argues that in addition to the form plus color pathway, there is also a system devoted to "dynamic form", which is associated with the magnocellular pathway.

The significance of this new conception of the visual pathways in interpreting the interference data is that if the pathway for form perception is less segregated than that for color or spatial perception, then a spatial task might be less disrupted by a color task than by a form task. Moreover, a color task would be expected to interfere with a form task since these are represented by a single population of cells in the higher visual areas. On this view, both color and form perception tasks will interfere with object imagery, and although a form perception task might produce greater interference (cf. Logie, 1986) it will also interfere with spatial imagery to a greater extent than would color.

Experiment 2

Imagery mediates not only recall of visual or concrete information, but comprehension of concrete material as well. Studies conducted by Arnold Glass and his collaborators have confirmed the role of imagery in sentence comprehension using a sentence verification paradigm in which subjects indicate whether statements are true or false. Following the distinction made by Glass, Eddy, and Schwanenflugel (1980), these studies have restricted "high imagery" statements to those for which an image is necessary in order to determine whether the sentence is true or false. Eddy and Glass (1981) found that while reaction times to verify high and low imagery statements are equivalent when an auditory presentation mode is used, low imagery statements are verified more quickly when the statements are presented visually. They concluded that

> ... reading interfered with the comprehension of high-imagery sentences because reading the words and representing the meaning of a high-imagery sentences both *require* visual representation (p. 342).

A later study by Glass, Millen, Beck and Eddy (1985) evaluated a number of different hypotheses regarding the source of the interference by using a variety of presentation conditions. To test the hypothesis that interference occurs because of the eye movements that reading requires, Glass et al. included left-to-right and Rapid Serial Visual Presentation (RSVP) formats. In the RSVP presentation format, each word appears in the same central location. These conditions were crossed with both a slow (120 words/minute) and a fast (220words/minute) rate. An auditory presentation format was also used. This study replicated the findings of Eddy and Glass (1981) by showing that high and low imagery sentences were verified equally quickly when auditorily presented, while collapsed across reading conditions high imagery sentences were verified more slowly. Nevertheless, no interaction between

type of visual presentation and imageability was found.

A subsequent experiment reported by Glass et al. (1985) was more successful in clarifying the nature of the interference effect. The goal of this experiment was to determine whether reading would disrupt all visual images, or would differentially affect those with a strong spatial component. To decide between these possibilities, verification times for low imagery sentences and three subgroups of high imagery sentences were compared as a function of presentation modality. The three subgroups consisted of sentences that involve verification of 1) color, 2) form or shape, and 3) spatial location or direction of movement.

Glass et al. report significant interactions between imageability and presentation modality for both the spatial and form imagery sentences, but not for the color imagery sentences. There was also a significant interaction between modality and type of imagery when only the form/shape and spatial imagery sentences were considered. The authors therefore conclude that reading interferes with the spatial component in imagery.

These findings are in accordance with the explanation of interference effects developed in this thesis. However, reading differs from listening not only in having a spatial component, but also in being a visual task. Therefore, a more rigorous test of the spatial interference hypothesis would involve a comparison of presentation formats in which the spatial component varies while presentation modality is held constant. Experiment 2 compared verification times for abstract, object imagery, and spatial imagery statements using these spatial and nonspatial visual presentation formats.

Method

Subjects. The subjects were 60 Duke undergraduates who participated for

course credit. Subjects were run individually or in small groups. Missing data resulted from incorrect responses or from responses made either before or after the six second interval during which responses were collected. Four subjects with only missing data in a condition were replaced. One subject was replaced due to missing data in excess of 30% of the experimental trials. Thirty-percent missing data was selected as the criterion for inclusion because it replicates the criterion used by Glass et al. in Experiment 1, and because inspection of the frequency distribution of errors also indicated that the subject was an outlier.

Stimuli. True and false versions of the 48 test sentences used in this experiment appear in Appendix C. There were 16 abstract sentences, 16 object imagery sentences, and 16 spatial imagery sentences. Object imagery sentences describe the visual appearance of individual objects, e.g., "The stars on the American flag are white". Spatial sentences require the subject either to judge the spatial relationship between two imaged objects or to mentally scan a single image, however these images need not be vivid or elaborate, e.g., "A right handed hitter places his left side toward the pitcher". Abstract sentences, such as "A pound is a unit of weight that is heavier than an ounce" do not require an image in order to be verified. Many of the sentences used in Experiment 2 were adapted from Eddy and Glass (1981); a few sentences were also adapted from Goldenberg, Podreka, Steiner, Willmes, Suess, & Deecke (1989). Sentences were written so that they could not be answered prior to presentation of the last word.

Each block of three sentences contained one object imagery sentence, one spatial imagery sentence, and one abstract sentence, and each set of 2 blocks contained one true and one false sentence of each type. Two versions of the test stimuli were created, the only difference being whether the true or false form of

each sentence was used: If the true form of a sentence was used in version 1, the false form was used in version 2. Half of the subjects received each version.

Design and procedure. The experiment was executed using Micro Experimental Lab software for presenting stimuli and collecting responses. Each trial began with a "READY ?" prompt which was displayed in the center of the screen for 2000 msec. Sentences were presented one word at a time with each word displayed for 400 msec. Following presentation of the last word a question mark appeared in the center of the screen. Reaction time was measured from the onset of the question mark. A maximum reaction time of 6000 msec was allowed. If the subject did not respond within this interval the trial ended and the next began.

Two presentation formats were used. For the nonspatial presentation each word appeared in the center of the screen (RSVP). For the spatial presentation format, each word appeared centered over one of five predetermined locations. Determination of the position for each word was random with two constraints: First, that successive words did not appear in the same location and second, that the last word in the sentence did not appear in the central location. The latter restriction was incorporated to insure that subjects had to make an eye movement after the last word had been presented to fixate the question mark. Half of the subjects received the RSVP presentation first and the spatial presentation second, and half received the spatial presentation first and the RSVP presentation second.

Subjects verified 12 practice sentences in the first format, followed by 24 test sentences. They then verified a second set of 12 practice sentences in the alternate format, followed by 24 test sentences. Each of the two blocks included 8 sentences of each type, half of which were true and half were false. Subjects were instructed to read each statement and indicate whether it was true or false by

pressing the appropriate key. They were asked to keep their right index finger on the true key and their left index finger on the false key, and to respond as quickly as possible without making a mistake.

To assess the possibility that interference effects depend either on imagery vividness, spatial ability, or both, following the sentence verification portion of the experiment each subject completed Marks' (1973) Vividness of Visual Imagery Questionnaire, followed by the Space Relations Form of the Differential Aptitude Test, Form T. These individual differences tests were selected as indices of object and spatial imagery ability because in studies using factor analysis to explore individual differences tests, the VVIQ and DAT have had high loadings on the "vividness and control" factor and on the "spatial manipulation" factor, respectively (Lorenz and Neisser, 1985; also see Garro, 1982)

Results.

Accuracy. Errors were analyzed using a 2 (truth value) x 3 (sentence type) X 2 (presentation format) repeated measures MANOVA. As previously noted, errors included both incorrect responses and failures to respond during the 6-second interval during which responses were recorded. The analysis indicated a main effect of truth value, $F(1,59)= 31.77$, $p < .0001$. More errors were made on the false items ($M=4.67$) than were made on the true items ($M=3.27$). The main effect of sentence type was also significant, $F(2,58) = 26.40$, $p < .0001$. Contrasts among the means for sentence type indicated that more errors were made on the spatial imagery sentences ($M=3.82$) than on the abstract sentences ($M=1.90$), $F(1,59)=50.29$, $p < .0001$. The number of errors made on the spatial sentences was also higher than the number of errors made on the object imagery sentences ($M=2.22$), $F(1,59) = 34.02$, $p < .0001$. No other main effects or interactions

were significant. The findings of the error data mirror those of the reaction time data reported below. There is therefore no evidence of a speed-accuracy tradeoff.

Reaction time. Only correct responses were considered in the reaction time analyses. In addition, three sentences were excluded from analyses of the reaction time data because the number of subjects who responded correctly fell within one standard deviation of the mean for guessing, assuming the binomial distribution. The high error rates on these sentences indicated that they were unusually difficult, and further suggested that a large majority of subject responses, including correct responses, may have been guesses. The three sentences that were eliminated were all spatial imagery sentences. All reaction time analyses were performed on the means of all correct items in a condition.

A 2 (truth value) x 3 (sentence type) X 2 (presentation format) repeated measures MANOVA performed on the reaction time produced main effects for all three factors. As there were no interactions with truth value, the means for sentence type by presentation format are presented in Table 2. True sentences were verified faster than false sentences (1308 msec vs 1500 msec), F (1,59)= 31.66, p < .0001. Sentences were also verified more quickly when they were presented in the RSVP format (M= 1262 msec) than when they were presented in the spatial format (M= 1546 msec), F(1,59)= 32.43, p < .0001. Finally, there was a main effect of sentence type, F(2,58)= 41.73 p < .0001. Spatial imagery sentences were verified more slowly than object imagery sentences (1730 msec vs 1280 msec), F (1,59)=71.00, p < .0001. They were also verified more slowly than the abstract sentences (M=1201 msec) F (1,59)=83.65, p < .0001. The difference between the object imagery and abstract sentences was also significant, F (1,59)= 6.92, p < .05.

Table 2

Mean Reaction Time (in msec) and Standard Deviations (in Parenthesis) To Verify Sentences as a Function of Sentence Type and Presentation Format

Format	Sentence Type		
	Abstract	Object	Spatial
RSVP	1115 (447)	1127 (387)	1545 (642)
Spatial	1288 (424)	1434 (386)	1916 (654)

The interaction between sentence type and presentation format was significant F(2, 58)= 3.54, $p < .05$. The source of this effect is revealed by examining the interaction in three separate planned 3-way MANOVA's, each comparing only two sentence types. First, the abstract sentences were compared with each of the high imagery subgroups in two separate analyses. The interaction between presentation format and sentence type was significant both with abstract and spatial imagery sentences, F(1,59)= 4.05, $p < .05$ and with abstract and object imagery sentences, F(1,59)= 6.43, $p < .05$. Second, an analysis was performed to test for an interaction between presentation format and type of imagery with the object and spatial sentences. This interaction was not significant, $F < 1$.

The large variability in the reaction time data may make it difficult to detect a subtle difference in the effects of the spatial presentation on the two types of imagery sentences used here. Because the expected interaction between presentation format and type of imagery was not found, a log transform was applied

to the reaction time data to reduce the variability, and an analysis of the log reaction times was conducted with the object and spatial sentences. This analysis yielded main effects of format, truth value, and sentence type, but the interaction between sentence type and presentation format was not significant, $F < 1$.

The results of analyses on both the untransformed and log transformed data indicate that the spatial presentation format slowed verification of the object and spatial imagery sentences to the same extent. Yet comparisons between the abstract sentences and each of the high imagery subgroups demonstrated that increasing the spatial component in the presentation mode does have a selective effect on high imagery material. This result stands in contrast to the findings of Glass et. al (1985), who failed to obtain an interaction between visual presentation format and imageability. The disparity in the conclusions regarding the effects of spatial and nonspatial formats on high and low imagery sentences probably reflects differences between the two studies in the strength of the spatial manipulation. That is, the present study compared the RSVP format to one in which words occurred in unpredictable sequences of five locations while Glass et al. compared the RSVP format to a left-to-right format. Though the left-to-right presentation is no doubt more spatial than the RSVP mode, it is less spatial than the spatial format used here, and more highly practiced.

Given the apparent effectiveness of the format manipulation, it is necessary to provide an account of why high imagery material is more interfered with by spatial processing, but spatial imagery is not differentially affected. An explanation that seems consistent with these findings is that all images are spatial, however this position is difficult to reconcile with accumulating evidence on the physiological bases of the two systems.

A second possible reason for the failure to obtain the predicted interaction between type of imagery and presentation format is that the two groups of high imagery sentences are equally spatial. At this point it is necessary to acknowledge that what is meant by the term spatial is far from clear.

In introducing the distinction between sentences that have a spatial component and those that do not, Glass et al. (1985) suggest that "spatial" sentences are those that require a "three dimensional" representation. They note that "... spatial images are assumed to ... contain information about distance or direction in space (depth)" (p. 454), and define their subset of spatial sentences as requiring analysis of "spatial location or the direction of movement" (p. 454). Consistent with this position, other investigators have noted that many tasks involving movement interfere with imagery and have attempted to describe the conditions under which movement interferes with imagery (e.g., Quinn & Ralston, 1986; Quinn, 1988). However, Smyth and Scholey (1994) found that memory for a sequence of locations is disrupted when subjects attend to tones emitted from different locations in space and verbally indicate the directions from which they came. This suggests that spatial imagery is disrupted by the requirement to shift attention to different spatial locations, even when no movements are required.

Other investigators have also considered imagery to have an attentional component. For example, Kosslyn (1993) refers not to spatial imagery but to "attentional imagery". He writes:

> ... if one stares at a tile floor and "sees" patterns by attending to different combinations of tiles, one is using attention-based imagery. This sort of imagery involves "marking" regions of a spatially organized structure... (p 270)

On the other hand, Logie (1989) suggests that imagery may include both a

"passive visual store" and an "active visual rehearsal process". Logie and Marchetti (1991) characterize the latter function as "...related to the control of movement...[and] akin to some form of mental scanning of the visual representation" (p. 113). The two functions they describe may be equivalent to the concepts of object and spatial imagery. In particular, notions of both movement and attention are embodied in the "rehearsal process".

Spatial imagery may also be operationally defined. For example, according to Quinn (1991), Baddeley and Lieberman (1980) "implicitly" define spatial processing as that which is interfered with by tracking a pendulum on the basis of auditory information. In the present study, spatial imagery may be operationally defined in terms of the extent to which the spatial presentation format impedes verification. An appropriate measure of this spatial interference is calculated by subtracting, for each sentence, the mean reaction time for the RSVP presentation from the mean reaction time for the spatial presentation.

Appendix D presents the sentences used in Experiment 2 in descending order according to this reaction time difference. If the initial classification of statements was correct, the spatial sentences should have the largest reaction time differences. An examination of the rank order of sentences shows that this is not the case. Nevertheless, it may be possible to refine the definition of spatial by assuming that the reaction time difference provides an index of the contribution of spatial imagery. This exercise led to several reinterpretations of the original sentence classifications, aided in part by other graduate and undergraduate students, whose introspections and interpretations were solicited.

Two sentences that were initially classified as abstract but produced large reaction time differences are "Spring is the only season between winter and

summer/autumn" (true/false) and "In a variety of different genres the introduction precedes/follows the conclusion (true/false). Considering these sentences in light of the large reaction time differences associated with them suggests that subjects may make temporal judgments by first translating the temporal information into an analog spatial representation. Consistent with this possibility, Friedman (1983) found that some types of judgments concerning the order of the months of the year are disrupted if subjects are simultaneously required to make systematic arm movements.

There was also some consensus that a shared and distinguishing characteristic of many of the sentences with large reaction time differences is that they require movement of either the imaged object or the viewer. For example, in describing the image generated by the sentence "When papers are stapled together the number of holes in each piece of paper is two/three (true/false)", one student reported that she imagined the action of taking out the staple, and then counted the holes. This suggested that the spatial presentation might have the greatest detrimental effect on those statements that involved movement.

To further explore this possibility, a norming study was conducted using 48 stimulus sentences used in Experiment 2, as well as 48 new sentences.

Norming Study

Method

Subjects. Twenty Duke undergraduates participated for class credit. No subject had participated in Experiment 2.

Materials and Procedure. Two versions of the stimuli were written, so that version 2 contained the complementary truth values used in version 1. For each sentence, subjects indicated 1) whether each sentence was true or false, 2) whether

or not an image was necessary to verify the sentence, and 3) whether they experienced a sense of movement as they judged the truth of the sentence.

Results.

Mean movement and imagery ratings are shown in Table 3. These were analyzed using planned contrasts to compare the means for the three sentence types. More subjects rated the spatial imagery sentences as evoking a sense of movement than both the object imagery sentences, F(1,19)=201.65, $p < .0001$, and the abstract sentences, F(1,19)=188.75, $p < .0001$. In addition, the object imagery sentences evoked more movement than the abstract sentences, although the magnitude of this effect is much smaller, F(1,19)= 15.55, $p < .001$. Imagery ratings for the abstract sentences were significantly lower than for both the spatial imagery, F(1,19)=860.43, $p < .0001$ and object imagery sentences, F(1,19)= 252.45, $p < .0001$. Imagery ratings for the object imagery sentences were lower than those associated with the spatial sentences, however the difference between these two types of sentences was not as great, F(1,19)=10.91, $p < .005$.

Table 3

Mean Percentage Raters Reporting That An Image Was Necessary For Sentence Verification And That A Sense of Movement Was Experienced and Standard Deviations (in Parenthesis)

Sentence Group	Imagery Needed	Sense of Movement
Spatial	.93 (.09)	.57 (.19)
Object	.80 (.20)	.08 (.08)
Abstract	.05 (.09)	.02 (.03)

Based on the results of the norming study, it appears that the sentence classifications used in Experiment 2 are valid ones: For both subgroups of imagery sentences, more raters reported that verifying the sentence required an image, compared to the abstract sentences. Moreover, the spatial imagery sentences, as a group, induced a sense of movement in a higher percentage of subjects than either the object imagery or abstract sentences.

Even if manipulations of both sentence type and presentation format are valid and effective, it is possible that the predicted interaction between type of imagery and presentation format would be mediated by individual differences in imagery ability. These therefore were investigated by classifying subjects according to their VVIQ and Space Relations scores, and including these as variables in the reaction time analysis.

Individual Differences Measures

Subjects were divided into high, medium, and low vividness groups on the basis of their VVIQ scores, and high, medium, and low spatial ability groups on the basis of their Space Relations scores. For both vividness and spatial ability groups, subjects were divided as nearly as possible into three groups of equal size, without violating the principle that all subjects with a given score be assigned to the same group. For all instances in which division into equal thirds would result in subjects with the same score being assigned to different groups, all subjects with that score were assigned to the "medium" group. There were therefore 18 high vividness (M score=66.22), 22 medium vividness (M score=56.82), and 20 low vividness (M score =47.65) subjects. There were 20 high spatial ability (M score=53.25), 21 medium spatial ability (M score=43.29), and 19 low spatial ability (M=34.21) subjects.

Since an interaction between presentation format and imageability was found even when individual differences are not taken into account, and because the primary rationale for Experiment 2 is to demonstrate a difference between object and spatial imagery, analyses conducted to explore the effects of individual differences did not include the abstract sentences. A 2 (truth value) x 2 (sentence type) x 2 (presentation format) x 3 (vividness group) x 3 (spatial ability group) mixed MANOVA was performed with vividness and spatial ability groups as between-subjects factors. This analysis produced significant main effects of truth, sentence type, format, and spatial ability group. In addition, sentence type interacted with both vividness group and spatial ability group, indicating that reaction times to verify different types of statements varied as a function of imagery vividness, F (2,51)=3.63, $p < .05$, and spatial ability, F (2,51)= 4.64 $p < .05$. Of particular interest, however, is the higher order interaction between spatial ability, sentence type, and format, F (2,51)= 3.40, $p < .05$.

Inspection of the mean reaction times for the object and spatial imagery sentences as a function of presentation format and spatial ability group (shown in Table 4) suggests that the increase in reaction time to verify the spatial sentences when they are presented in the spatial format as compared to the RSVP format is much larger for the medium and low spatial ability groups than it is for the high spatial ability group. In contrast, the increase in time to verify the object imagery sentences when they are presented in the spatial format seems roughly equivalent for all three groups.

Table 4

Reaction Times (in msec) and Standard Deviations (in Parenthesis) to Verify Object Imagery and Spatial Imagery Sentences as a Function of Presentation Format and Spatial Ability

	Spatial Ability		
	High	Medium	Low
Spatial Sentences			
spatial format	1703 (606)	1827 (600)	2238 (666)
RSVP format	1589 (429)	1278 (700)	1792 (678)
spatial-RSVP	114	549	446
Object Sentences			
spatial format	1360 (346)	1405 (360)	1543 (447)
RSVP format	1001 (385)	1131 (346)	1253 (408)
spatial-RSVP	359	274	290

This pattern was confirmed by combining the low and medium spatial ability groups and performing two separate analyses, one to test the interaction between spatial ability (high versus low/medium) and format with the object imagery sentences and a second to test this interaction with the spatial imagery sentences. As expected, for the object imagery sentences, the interaction between format and spatial ability (high versus low/medium) was not significant, $F < 1$. For the spatial imagery sentences, the interaction between format and spatial ability (high versus low/medium) was significant, $F(1,58) = 4.05$, $p < .05$. These analyses suggest that when the sentence to be verified requires object imagery, the spatial

presentation format produces an equivalent increase in reaction time for both high and low/medium spatial ability groups. When the sentence to be verified requires spatial imagery however, the extent to which the spatial presentation format slows verification time is a function of spatial ability. These results therefore suggest that the interaction between format and imagery type may occur only in subjects of low/medium spatial ability. To test this effect, the 2 (truth value) x 2 (sentence type) x 2 (presentation format) was performed again with only the medium/low subjects to test for the interaction between format and sentence type with the object and spatial sentences. This effect was marginally significant F (1,39) =4.02, p = .052.

Discussion

Experiment 2 was designed to test the hypothesis that reading interferes with imagery only when both require spatial processing. The findings tentatively suggest that this effect obtains only for subjects of lower spatial ability. For these subjects, the increase in reaction time associated with the spatial presentation format is higher for sentences requiring spatial imagery than it is for sentences requiring object imagery. For subjects with high spatial ability, however, the increase in verification time that occurs as a result of the spatial presentation format is actually higher with the object imagery sentences than with the spatial imagery sentences.

The mediating effect of spatial ability is easily accommodated by the logic of the selective interference paradigm, in which it is supposed that interference reflects competition for shared (neural) resources: High spatial ability subjects are able to process spatial information more efficiently, and are therefore able to perform the imagery and perceptual tasks without exceeding the available spatial resources, therefore no interference is observed.

The interaction between presentation format and imageability could be

alternatively explained in terms of general difficulty. This account would argue that the interaction merely reflects greater than additive effects of combining the more difficult presentation format with the most difficult sentence comprehension task. Future experiments might compare the difficulty and selective interference interpretations by comparing the RSVP format to one that makes greater demands on the object system, e.g., by degrading the words. If the interaction between presentation format and sentence type is an artifact of task difficulty, then perceptual degradation would also be expected to selectively slow verification of the spatial sentences. On the other hand, if the interaction reflects the functional architecture of the perceptual and imagery systems, then perceptual degradation might be expected to selectively slow verification of the object imagery sentences.

Experiment 3

Although the existence and relative independence of object and spatial imagery has received converging support from neuropsychological, psychophysiological, behavioral, and psychometric studies, the term "spatial" has never been clearly defined. Experiment 3 was originally conceived as a means of exploring the meaning of the term "spatial" by using a behavioral manipulation with high face validity and measuring the physiological correlates of the task. The physiological measures have not been obtained, however the behavioral results are inherently informative because although a significant amount of research has been devoted to establishing the existence of two imagery systems, less effort has been directed towards isolating the roles of these systems in memory. Studies that report the potent effects of imagery typically do not distinguish between object and spatial imagery.

There is a large body of literature on spatial memory, however. These studies indicate that spatial location is an important attribute of memory (Underwood, 1969), and may be automatically encoded (Hasher & Zacks, 1979; Ellis 1990; Andrade & Meudell, 1993). For example, recall for the location of information in a text is reliable even when subjects are not specifically instructed to learn this information (Rothkopf, 1971; Zechmeister & McKillip, 1972). Memory for the locations of objects is even more accurate than memory for the location of words with the same referents (Pezdek, Roman, & Sobolik, 1986).

Given that memory for location is reliable and automatic, does the provision of a spatial organization also improve memory for the items associated with those locations? Winograd and Church (1988) report that the learning of associations among attributes of a single stimulus is facilitated when the locations in which the

stimuli appear remain constant. They propose that the observed facilitation is due not to a strengthening of associations between the stimulus attributes, but to the use of location as an added cue. If location serves as any other cue, then recall of individual items might also be enhanced when items to be learned are presented at different spatial locations, rather than all in the same location.

The effectiveness of pairing items to be learned with unique locations is apparent in the method of loci. To use the method of loci to learn a list of items, one imagines walking a familiar route and stopping at predetermined points to imagine one item in each setting. The items are later retrieved by imagining walking the path and "seeing" what was deposited at each location. The method of loci seems to rely on spatial imagery, however, as advocated in the *Ad Herennium*, each location is generally a distinct vividly imagined setting (Yates, 1966). It is therefore possible that the different locations simply provide visually distinctive (object) images with which to pair the to-be-learned items. On the other hand, Cicero stated that "...the order of the places will preserve the order of the things... (in Yates, 1966 p. 2, and cited in Paivio, 1971), which suggests that location permits a retrieval strategy that fixes the order of recall.

The function of sequencing information has not traditionally been ascribed to mental imagery, however. Healy (1977) argues that temporal order recall is mediated by a phonemic code rather than a visual code, as indicated by phonemic substitutions and by the effects of interpolated vocalization (versus an interpolated spatial task). Paivio (1971) maintained that imagery was less suited for sequential memory than the verbal system, and that this was a consequence of inherent differences in the modalities with which these memory systems are allied: Imagery, like vision, is basically a parallel system; verbal memory, like speech, is inherently

sequential. Paivio illustrated the difference between the two systems with the following observation: In describing the layout of a room from memory, it is possible to begin from any one of many starting points. To recall verbal material, like a poem, however, it is easiest to begin at the beginning. According to Paivio then, a distinguishing feature of the imagery system is that there are no constraints on the order in which information can be retrieved from it.

Yet while Paivio's general characterization of imagery is that it is a parallel system, he also acknowledged that a sequential organization could be imposed on the imagery representation. He wrote:

> Imagery, therefore, is basically a parallel-processing system... It is not specialized for serial processing unless linked to an integrated (symbolic) motor response system, such as might be involved in imaginally tracing the outline of a block letter... or imagining oneself moving along a familiar route containing sequentially arranged 'signposts' as advocated in one version of Simonides' technique of places and images... (p 180).

Given the distinction between object and spatial imagery, it now seems possible that Paivio's general view of imagery corresponds to object imagery, while the serial processing function he refers to corresponds to one aspect of spatial imagery. If spatial imagery serves a sequencing function, as Paivio and Cicero suggest, then a spatial manipulation would be expected to preserve order, independent of amount recalled. Therefore although there may be no benefit of a spatial organization on serial recall even when spatial and temporal order are redundant (Hitch and Morton, 1975), an advantage may be observed with a more sensitive measure, such as scoring the number of sequencing errors.

Experiments 3 sought to isolate the contribution of spatial imagery to both the number of items recalled and to their serial order by presenting objects to be remembered either in a single location or in different consecutive locations. Serial

recall instructions were used, and both serial recall and sequencing errors were scored. A second factor in the experiment was presentation rate. It was not certain that an effect of the spatial manipulation would be found with only a single presentation of the stimuli. Two presentation rates were therefore included to determine whether the effects of the spatial manipulation would emerge only under a distributed presentation, or would generalize to both single and distributed presentation conditions. Experiment 4 further investigated the conditions under which spatial location aids memory by presenting the items in random, rather than consecutive, locations in the array. Experiment 5 extended the findings of the earlier experiments by including a condition in which items appear in a random sequence of locations but some subjects are reminded of the sequence of locations at retrieval. This manipulation was intended to investigate whether a known sequence of random locations would permit sequencing.

Method

Subjects. Fifty-six Duke undergraduate students participated to fulfill a course requirement. Subjects were assigned to conditions based on the order in which they signed up to participate, and were run in small groups.

Stimuli. Subjects were shown four sets of 24 pictures previously normed to each have one name (Snodgrass & Vanderwart, 1980). Each picture was photographed in two different settings. For presentation in the spatial condition, each picture was photographed in one of the cells of a 6 x 4 matrix. Each set included one picture in each of the 24 matrix cells. For the nonspatial condition, each picture was photographed surrounded by a square frame of the same dimensions as one of the matrix cells. Photographs were mounted as slides. For the spatial presentation, items were individually presented in successive cells of the

matrix. To maximize the distinctiveness of the spatial locations, the 6 x 4 matrix was divided into four 3 x 2 matrices and the order of presentation was left to right and top to bottom in each of these four quadrants, as depicted in Appendix E. The projected matrix was approximately 1.40 m high x 2.40 m wide. For the single location presentation, each item appeared in a central location. The projected frame in which each item appeared was approximately 34 cm ^{2}. Subjects viewed the stimuli from distances ranging from 2.75 m to 5.25 m. The order of items within each set was identical for the matrix and single location formats.

Apparatus. Slides were presented using a Kodak carousel 850H projector, connected to a mechanism that controlled the timing of slide presentation.

Design and Procedure. Half the subjects were assigned to the spatial condition, and half were assigned to the single location condition. Within each condition, subjects received one of two orders of the four lists of 24 slides. Half of the subjects in each condition saw sets in the order 1-4, while the other half saw them in reverse order. The two presentation rates were a 3-second condition, in which each set was presented once at a 3-second rate, and a 1-second condition in which each set was presented three times in succession at a rate of 1 slide per second. Presentation format, rate, and order served as between-subjects variables.

Subjects were instructed to try to remember the pictures by silently naming each item and forming a clear image of it. They were informed that they would later be asked to recall the items in serial order. After each set had been presented subjects worked on letter sequence puzzles for 30 seconds. They were then given a minute and a half to write down as many items as they could recall in serial order.

Results.

Each recall protocol was scored in two ways. Serial recall was scored by

omitting the minimum number of items necessary to leave the remaining items in correct order. In a few rare cases in which an items was written twice, the second instance was ignored. Synonyms and responses that named items visually similar to the target were scored as correct, e.g., "bracelet" for chain, or "squirrel" for skunk.

Serial Recall. Serial recall was analyzed using a mixed 2 (presentation format) x 2 (presentation rate) x 2 (set order) x 4 (trial) MANOVA with trial as a repeated factor. Presentation format did not affect amount recalled (spatial = 8.89, nonspatial= 8.97, $F < 1$). There was a significant main effect of presentation rate: The mean number of items recalled with three successive presentations at 1-second (9.73) exceeded the number recalled with a single 3-second presentation (8.13), $F(1,48)= 5.29$, $p < .05$. There was also a trial x set order interaction, $F(3,46) = 7.13$, $p < .0005$, indicating that at least one of the four sets was easier to recall.

Sequencing errors. A second MANOVA was performed on the number of sequencing errors, calculated as a proportion of the total number of items recalled regardless of order. The number of sequencing errors is expressed as a proportion because of the tendency for more items to be recalled when they appear in a single location. To rule out the interpretation that subjects in the single location condition make more sequencing errors simply because they recall more items, errors are expressed as a proportion of amount recalled. The analysis of sequencing errors yielded a main effect of presentation format, $F(1,48)=19.79$, $p < .0001$. When items were presented in a single location subjects recalled 20 % of the items out of order, however when they were spatially presented only 8 % were recalled out of order. Mean sequencing errors for the single location and matrix presentation

formats at each presentation rate are shown in Table 5. No other main effects or interactions reached significance.

Table 5

Mean Proportion of Sequencing Errors and Standard Deviations (in Parenthesis) for Conditions in Experiment 3

Rate	Matrix	Single
1-sec	7(6)	18(9)
3-sec	9(13)	21(10)

Discussion

These data indicate that while presenting visual stimuli in a spatial array does not increase the amount recalled, it does reduce the number of sequencing errors. Moreover, this effect obtains both when the stimuli appear once for a period of 3-seconds and when they appear three times for 1-second apiece. It seems likely that presenting items in consecutive spatial locations preserves temporal information because spatial and temporal order are perfectly correlated, permitting knowledge of the spatial locations to be translated into knowledge regarding temporal order. This in turn suggests that the effects of providing a spatial organization may depend on whether or not spatial and temporal order are redundant. Experiment 4 investigates whether the advantage of a spatial organization holds when temporal order is not predictive of spatial order.

Experiment 4

Experiment 4 used the same procedure as Experiment 3, except that items in the spatial format were presented in nonsequential cells of the matrix, and a different random sequence of locations was used for each of the four sets.

Method

Subjects. Fifty-six Duke undergraduate students participated to fulfill a course requirement. No subject had participated in Experiment 3. Subjects were assigned to conditions based on the order in which they signed up to participate, and were run in small groups.

Stimuli. The 4 sets of slides used in Experiment 3 served as stimuli. Within each set, however, the slides were randomized so that in the spatial condition the items would appear in nonconsecutive cells of the matrix. The order in which the items were presented was the same for both spatial and single location formats.

Design and Procedure

The procedure was the same as that used in Experiment 3. Both the 1-second and 3-second presentation rates were used. Within each of these conditions, half of the subjects saw the items within a matrix, and the other half saw the items within a frame equivalent in size to a single matrix cell. As before, two set orders were used, one being the reverse of the other.

Results.

Serial Recall. Serial recall was scored as in the previous experiment. The data were analyzed using a mixed 2 (presentation format) x 2 (presentation rate) x 2 (set order) x 4 (trial) MANOVA with trial as a repeated factor. As in Experiment 3, more items were recalled at the 1-second presentation rate than at the 3-second rate

(10.06 vs 7.94 respectively, $F(1,48)=4.84$, $p < .05$). This effect was qualified by a higher order presentation rate x trial x set order interaction, $F(3,46)=3.14$, $p < .05$, indicating that the relative difficulty of the 4 sets varied with the rate of presentation.

Sequencing Errors. A second analysis was done with sequencing errors as the dependent measure. This analysis yielded a main effect of presentation rate. Subjects who received three presentations at the 1-second rate made 20 % sequencing errors, compared to 30 % for the single 3-second presentation. A presentation rate x trial x set order interaction was also found, $F(3,46)= 3.17$, $p < .05$. In contrast to Experiment 3, however, there was no difference between the two presentation formats in the proportion of items recalled out of sequence (random spatial= 27 %, nonspatial= 23 %, $F = 1.02$). Mean sequencing errors for the two presentation formats as a function of presentation rate are shown in the right-hand panel of Table 6, with the findings of Experiment 3 on the left.

Table 6

Mean Proportion of Sequencing Errors and Standard Deviations (in Parenthesis) for Conditions in Experiments 3 (Sequential) and 4 (Random)

	Sequential			Random	
Rate	Matrix	Single	Rate	Matrix	Single
1-sec	7(6)	18(9)	1-sec	25(14)	14(10)
3-sec	9(13)	21(10)	3-sec	29(19)	32(14)

Discussion

The findings of Experiment 4 indicate that the smaller proportion of sequencing errors associated with the spatial presentation in Experiment 3 does not obtain when the locations in which the items appear are nonsequential. These results suggest that the spatial organization is only beneficial when the series of locations can be reconstructed at the time of retrieval. In other words, it seems plausible that the random sequence does not confer an advantage because subjects could not recall the sequence of locations in which the stimuli appeared, and were therefore unable to use this information to remember the order in which the items appeared.

This interpretation is consistent with the findings of a main effect of presentation rate on sequencing errors in Experiment 4 but not in Experiment 3. Though not directly tested in this study, the superior recall associated with three successive 1-second representations might be expected to extend to recall of the sequence of locations used, as well as for the items themselves. On this interpretation the sequential order used in Experiment 1 was sufficiently easy that it could be learned equally well in the 1-second and 3-second conditions. Consequently, there would be no effect of presentation rate on sequencing errors. In Experiment 4, however, recall of the sequence of locations themselves might be expected to benefit from the distributed presentation. This in turn would be reflected in a reduced number of sequencing errors. The interaction between presentation format and rate that is predicted by this hypothesis approaches but does not reach significance, F (1,48)=2.89, p= .096. The main effect of presentation rate on sequencing errors may also result from an increase in the strength of item to item associations.

A slightly different way of framing the hypothesis is to suggest that a

sequence of locations can become encoded in memory as a spatial pathway, and that this pathway can be used to remember a sequence of events. This account would explain the effect of presentation rate on sequencing errors by supposing that when subjects see the sequence of locations three times, the random locations begin to form a pathway. According to this view, the consecutive locations used in Experiment 1 are effective because they constitute an easily learned pathway. To further explore the plausibility of this idea, Experiment 5 included retrieval cues that could be used to indicate the sequence of locations in which the stimuli appeared. By pairing such cues with a random spatial presentation the learning of a spatial pathway can be simulated.

Experiment 5

In the third experiment single location, sequential-spatial, and random-spatial presentation formats were used. In addition, subjects were provided with retrieval cues during the recall period. Retrieval cues were of two types: 1) spatial cues in which arrows were used to indicate the order of locations in which the stimuli had appeared or 2) single location cues in which each arrow pointed to the same central location.

Five conditions were used in Experiment 5. In the single location control condition, all stimuli and retrieval cues were shown in a single central location. There were also four spatial conditions given by pairing each of the two spatial presentation formats with both spatial and single location cues. For the sequential-spatial condition with spatial cues, both stimuli and arrow cues were displayed in sequential cells of the matrix. For the random-spatial condition with spatial cues, the arrows were displayed in the same random sequence of locations as that in which the stimuli appeared. A different sequence of locations was used for each of the 4 sets in the random-spatial conditions.

Comparisons between the single location format and both the sequential-spatial and random-spatial formats with single location retrieval cues were expected to replicate the findings of Experiments 3 and 4. In particular, sequencing errors should be significantly lower when stimuli appear in the sequential-spatial format than when they appear in a single location. It was further predicted that because the order of locations is easily learned when they are consecutive, the spatial cues would provide no additional information in the sequential spatial condition. Therefore no difference between the spatial and nonspatial cue conditions was expected when stimuli appear in a sequential-spatial format. A comparison between

the single location and random-spatial format with single location cues was expected to replicate the finding of Experiment 4 that the random-spatial presentation provides no advantage in sequencing. However, it was predicted that when spatial cues were given at retrieval, sequencing errors should be lower than when all stimuli appear in the same location. This finding would provide evidence that a spatial presentation format is beneficial if the sequence of locations in which the items appeared can be reconstructed at the time of retrieval.

Method

Subjects. Eighty undergraduate students participated to fulfill a course requirement. No subject had participated in either Experiment 3 or Experiment 4. Subjects were assigned to conditions based on the order in which they signed up to participate, and were run in small groups.

Stimuli The stimulus items were the same as those used in Experiments 3 and 4, however for this experiment the 4 sets were reconstituted by randomizing the 4 slides for each of the 24 serial positions. The order in which the items were presented in the single location condition was the same as that used for the two sequential-spatial conditions.

Slides of the nonspatial retrieval cues were constructed by photographing an arrow pointing to a square frame, identical to that which surrounds each of the stimuli in the single location conditions. An example of a single location retrieval cue appears in Appendix E. Slides of the spatial retrieval cues were constructed by taking 24 photographs, each of which includes the matrix with an arrow pointing to one of the matrix cells.

The stimuli were projected using a Kodak projector. The projected matrix was 1.14 m high x 1.65 m wide. The dimensions of the single frame

was 28 cm ^{2}. Subjects viewed the stimuli from distances ranging from 1.45 m to 4.14 m.

Procedure. Stimuli were shown for 1-second apiece, with each set shown three times. After the third presentation, subjects worked on letter sequence puzzles for 30 seconds. Subjects were then shown the 24 arrow cues at a constant rate of about one every 5 seconds. Subjects in all conditions were told that they would be asked to recall the items in the order in which they were presented. For the two conditions in which spatial cues were provided, subjects were informed that the sequence of locations in which arrow cues appeared would be the same as the sequence in which the stimuli appeared, and that each time they saw an arrow cue they were to write down the name of the item that appeared in that location. For the conditions in which nonspatial cues were provided, subjects were instructed to write the name of the first item when the first cue appeared, the second item when the second cue appeared and so forth. All subjects were instructed to write down only 1 item for each arrow, and to put an "X" on the line if they could not recall an item. Two orders of set presentation were used, as in the earlier experiments. Presentation format and list order served as between-subjects variables.

Results.

Eleven subjects did not recall any items in the first set. As this was thought to reflect a failure to understand the instructions, set 1 was excluded from all analyses. In addition, 1 subject who did not recall any items from sets 1 and 2 was replaced. Recall protocols were scored in the same manner as in Experiments 3 and 4, except that items written twice were not scored. This change in the scoring procedure was necessary because of a few subjects who adopted the strategy of filling most of the response sheet with only a few items.

Serial Recall. Serial recall was analyzed using a mixed 2 (presentation format) x 2 (set order) x 3 (trial) MANOVA with trial as a repeated factor. Mean serial recall for the 5 conditions is presented in Table 7. There was a main effect of trial, $F(2,69)=6.50$, $p < .005$. The means for the three trials were: 8.28 (Trial 2), 9.43 (Trial 3) and 9.61 (Trial 4). There was also a main effect of presentation format, $F(4,70)=3.88$, $p < .01$. Tukey's HSD test on all main effect means indicated that serial recall in the two sequential-spatial conditions was higher than in the condition in which a random-spatial format was paired with spatial cues.

Sequencing Errors. Mean sequencing errors for the five conditions appear in Table 7. Two analyses of sequencing errors were performed. First, a single planned comparison was used to test the predicted ordering of the five conditions in the proportion of sequencing errors. The tested prediction was as follows: Performance should be lowest with the single location presentation and random-spatial format with single location cues; no difference between these conditions was expected. Performance should be highest in the two sequential spatial conditions; no difference between these conditions was expected. Finally, sequencing errors should be at an intermediate level when the random-spatial array is paired with spatial cues. This test for this ordering was significant, $F(1,70) = 29.43$, $p < .0001$. A second contrast was performed to test for a nonlinear component in this ordering by comparing the mean of the random-spatial presentation with spatial cues condition to the average of the four remaining conditions. As expected, this contrast was not significant $F(1,70) < 1$.

Table 7

Mean Proportion of Sequencing Errors and Standard Deviations (in Parenthesis) and Mean Serial Recall and Standard Deviations (in Parenthesis) for Conditions in Experiment 5

Condition	% errors	Recall
Single location/single location cues	20(13)	9(4)
Random-spatial/single location cues	20(16)	8(3)
Random-spatial/spatial cues	13(10)	7(2)
Sequential-spatial/spatial cues	6(6)	10(3)
Sequential-spatial/single location cues	5(4)	11(3)

Discussion

Experiment 5 replicated the finding of Experiment 3 that a lower proportion of sequencing errors is made when items to be remembered are displayed in consecutive locations. Also replicated was the finding of Experiment 4 that the benefit of the spatial organization is abolished when the order of locations is nonconsecutive. It was speculated that in order to benefit from the spatial presentation, the sequence of locations itself must be learned. Therefore, with no prior training, only a consecutive sequence is effective. On this interpretation the difference between the sequential-spatial and random-spatial formats is due to subjects' inability to reconstruct the random order of locations at the time of retrieval. The prediction that cues to the order of locations would allow subjects to benefit from the random-spatial presented received support in the present study.

General Discussion

The studies presented here suggest that one function of spatial imagery is to help preserve temporal information. The spatial and object imagery systems therefore seem to have complementary roles. The contrast between the functions of these systems is suggested by a comparison of two mnemonics, the pegword method and the method of loci. In the pegword mnemonic the numbers one through ten are each associated with a rhyming peg, e.g., one-bun, two-shoe, three-tree and so on. Each word to be learned is then paired with the pegword and an interactive image of the referents of these two words is constructed. For example, if the first word is "mouse", one might imagine a mouse gnawing on a hamburger bun. The target words are later retrieved in serial order by using the rhyme to recall the pegword, and then retrieving the image of the peg and target item.

Like the pegword mnemonic, the method of loci involves the construction of interactive images, and one function of the locations is to supply these object images. A second function of the locations seems similar to the function served by the numbers in the pegword mnemonic, i.e., to permit the stimulus images to be retrieved in sequential order. In this way the locations, like the numbers, function to organize retrieval of the stimulus images, thereby increasing the likelihood that none is forgotten. This hypothesis regarding the function of spatial imagery is similar to one suggested by Paivio (1971), namely to keep track of what has and has not been reported.

This function of the spatial pathway could be demonstrated by having subjects learn a list of item names by showing them a series of photographs and instructing them to imagine each item in the setting depicted by the photograph, e.g., a park bench for item 1, a factory chimney for item 2, etc.[1]. Presumably this

condition is akin to having subjects learn the items using the method of loci, except that photographs substitute for images and the loci do not constitute a path. At recall, subjects would be shown the series of photographs and asked to name the items. Although the locations, or settings, do not constitute a known pathway, this should not have a detrimental effect on performance since in this experiment there is no need to retrieve, or keep track of, the stimulus images.

If the sequential processing given by the spatial system permits more efficient retrieval (cf. Paivio, 1971), it is surprising that, in Experiment 3, serial recall is not improved by the spatial presentation. Equivalent serial recall for spatial and nonspatial presentation formats is also reported by Hitch and Morton (1975). In the present study, however, it is important to qualify the conclusion regarding the absence of effects on serial recall by noting that if item order is disregarded, i.e., if the recall protocols were scored as though subjects had been given free recall instructions, there is a tendency for subjects in the single location condition to recall more items than subjects in the spatial condition. It may be possible that redirecting attention to a new location for each item creates additional attentional demands or reduces processing time per item in the spatial condition. These effects may obscure the advantage of the spatial organization so that on a serial recall measure the performance of the two groups is equivalent. Given that the spatial condition permits temporal order to be retained, it is predicted that if the two groups were equated on the number of items recalled regardless of order, serial recall would be higher in the spatial condition. Nevertheless, it is clear from the studies reported here that an effect on serial recall would be secondary to a sequencing advantage that occurs independent of amount recalled.

Conclusion

The experiments reported in this thesis are behavioral investigations of two imagery subsystems. Experiment 1 was designed to provide evidence that the object and spatial subsystems can be behaviorally dissociated through selective interference, however the result that would have supported this conclusion, namely an interaction between imagery and perceptual tasks, was not found. In considering possible explanations for the failure to obtain this result, the most plausible seems to be that form or pattern perception is less segregated from the system devoted to movement than originally thought. Since the time Experiment 1 was designed, the descriptions of the underlying anatomical systems have evolved from a model emphasizing two highly segregated cortical systems to one in which four interconnected systems are recognized. Though evidence from a variety of methodologies confirms the basic division between a system devoted to location and one devoted to analysis of visual appearance, it appears that there are further divisions, less segregation of function, and a greater number of connections among these systems than previously thought. Interference effects in intact subjects may be especially sensitive to these factors.

The results of Experiment 2, which sought to confirm the spatial nature of the interference between reading and comprehending certain types of high imagery statements affirm the importance of considering individual differences in spatial ability. In particular, it is reasonable to expect that subjects of high spatial ability may not experience spatial interference at the same level of task difficulty because they are able to process spatial information more efficiently and so do not exceed the available spatial resources.The findings of this study, though not conclusive, are nevertheless promising. A future study is planned that makes specific predictions

about the mediating effects of spatial ability, and also includes a presentation condition that makes greater demands on object perception, e.g., adding color or degrading the words, to rule out a "general difficulty" interpretation of the expected interaction between sentence type and presentation format.

Despite the difficulty in separating the object and spatial systems through selective interference, Experiments 3-5 revealed that spatial imagery serves a memory function that is distinct from that served by the object system. This also constitutes a type of evidence for the existence of two imagery systems. In particular, the experiments presented here demonstrate that spatial imagery plays a role in sequencing events in memory.

This finding is important because although many studies attest to the mnemonic value of imagery, the experiments reported here isolate the contribution of spatial imagery. The suggestion that spatial imagery plays a role in preserving temporal order is particularly compelling in light of converging evidence from neuropsychology and from selective interference. For example, Critchley (1953) observed that a disturbance in temporal information was sometimes observed in patients with parietal damage. He wrote:

> Most interesting and complicated of all are those spatial disorders which also involve the conception of time, or order, or sequence. Thus, at the simplest level, is the patient who is able to count, but not backwards: to recite the days of the week (months of the year, or letters of the alphabet), but not in reverse order.... A less obvious defect is shown by the patients who cannot visualize in correct order a list of monarchs or prime ministers; who mix up the sequence of historical events. (p. 352)

Critchley's comments are consistent with Friedman's (1983) finding that judgments concerning the "backwards" order of the months of the year are susceptible to disruption by a nonvisual spatial task. These data suggest that subjects sometimes

reason about temporal information by translating it into a spatial representation. That translation seems essentially a reversal of what subjects were able to do when spatial and temporal order were correlated in Experiment 1, namely to convert information about the spatial locations in which the items appeared into knowledge of the temporal order in which they were presented.

The sequencing function of spatial imagery is also suggested by the nature of the spatial tasks used in two recent interference studies. In experiments by both Logie and Marchetti (1991) and Smyth and Scholey (1994) the spatial tasks are not simply memory for fixed locations, but rather memory for location sequences. Logie and Marchetti note that in a spatial task like Brooks' matrix task, the spatial system may only be engaged during encoding and retrieval because during the retention interval the locations can be imaged as a static pattern. They conclude that a spatial memory system is more likely to be involved when the order of locations must be retained. Smyth and Scholey further develop this idea by proposing that a sequence of locations is rehearsed using spatial attention.

One possibility is that what has been referred to as "spatial imagery" is in fact spatial attention acting upon representations supplied by the object system. Consistent with this interpretation is evidence from unilateral neglect, a disorder associated with posterior parietal damage that is characterized by failure to attend to the left side of space. Unilateral neglect manifests itself in imagery as a failure to report the left side of an image. In a striking demonstration of this deficit, Bisiach and Luzzatti (1978) asked patients to describe a familiar scene from one perspective, and then from the opposite perspective, so that what is initially on the left side of the image is subsequently on the right. They found that patients suffering from unilateral neglect fail to mention objects on the left side of the image. When

asked to reverse perspective, they name those objects previously omitted and omit those mentioned only moments before. This suggests that the stored representation is intact, and that impaired attentional processes underlie the failure to report certain details.

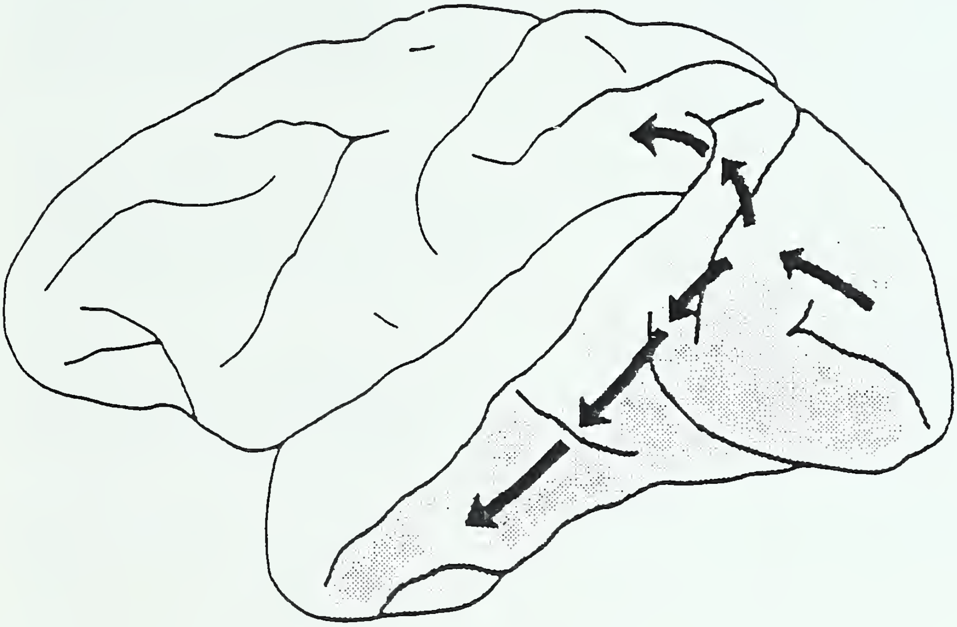
Spatial imagery may or may not be reducible to spatial attention. It now seems clear, however, that the spatial system operates upon object imagery in sequential fashion to permit more efficient retrieval of information and to preserve information regarding temporal order.

Notes

1. This hypothetical experiment is based on David Rubin's class demonstration of the method of loci.

Appendix A

Two cortical pathways



Arrows schematically show the two cortical pathways in the left hemisphere of a rhesus monkey. The two pathways begin in the primary visual cortex of the occipital lobe. The upper pathway extends to the posterior parietal lobe. The lower pathway extends into the inferior temporal lobe. Adapted from Mishkin, Ungerleider, & Macko (1983)

Appendix B

Stimulus Descriptions used in Experiment 1

Practice Trials

A. There is a baton
The curtain is above the baton
The canteen is above the curtain
The backpack is to the left of the canteen
The screen is above the backpack
The tank is above the screen

B. There is a dresser
The iron is to the right of the dresser
The truck is above the iron
The football helmet is to the left of the truck
The leaf is to the left of the football helmet
The television below the leaf

C. There is a basket
The couch is to the left of the basket
The celery is below the couch
The telephone is to the left of the celery
The umbrella is below the telephone
The anchor is below the umbrella

D. There is a peanut
The comb is below the peanut
The bow is below the comb
The thimble is to the right of the bow
The bread is above the thimble
The sailboat is to the right of the bread

E. There is a grape
The pocketbook is below the grape
The tennis racket is to the left of the pocketbook
The wrench is below the tennis racket
The watch is below the wrench
The lamp is to the right of the watch

F. There is a refrigerator
The whistle is the right of the refrigerator
The ashtray is above the whistle
The artichoke is to the right of the ashtray
The screw is below the artichoke
The ring is to the right of the screw

G. There is a coat
The well is to the right of the coat
The motorcycle is below the well
The pitcher is to the left of the motorcycle
The car is below the pitcher
The cherry is to the right of the car

SET I

A. There is a chain
The nut is below the chain
The bell is to the right of the nut
The baby carriage is above the bell
The light bulb is above the baby carriage
The needle is to the left of the light bulb

B. There is a desk
The cup is above the desk
The swing is to the left of the cup
The bed is above the swing
The violin is to the left of the bed
The harp is to he left of the violin

C. There is a sled
The spoon is to the left of the sled
The flute is to the left of the spoon
The doll is below the flute
The piano is to the right of the doll
The watering can is below the piano

D. There is a pencil
The plug is to the left of the pencil
The lock is above the plug
The tomato is to the left of the lock
The ruler is to the left of the tomato
The sweater is above the ruler

E. There is a (pair of) pliers
The toothbrush is to the left of the pliers
The jacket is above the toothbrush
The apple is to the left of the jacket
The helicopter is to the left of the apple
The rocking chair is below the helicopter

F. There is an orange
The top is below the orange
The gun is to the right of the top
The key is below the gun
The roller skate is to the left of the key
The airplane is below the roller skate

G. There is a fork
The banana is below the fork
The toaster is to the left of the banana
The mushroom is above the toaster
The mitten is to the left of the mushroom
The asparagus is below the mitten

H. There is a (pair of) glasses
The cake is above the glasses
The candle is to the left of the cake
The baseball bat is above the candle
The potato is to the left of the baseball bat
The table is above the potato

I. There is a football
The bottle is above the football
The bicycle is to the left of the bottle
The shirt is below the bicycle
The tree is to the left of the shirt
The chair is below the tree

J. There is a ladder
The shoe is to the left of the ladder
The window is below the shoe
The nail is below the window
The carrot is to the left of the nail
The pot is above the carrot

SET II

A. There is a doorknob
The crown is to the left of the doorknob
The wagon is below the crown
The stool is to the right of the wagon
The strawberry is to the right of the stool
The fence is above the strawberry

B. There is a (pair of) scissors
The vest is to the right of the scissors
The wheel is above the vest
The corn is to the right of the wheel
The clothespin is above the corn
The door is above the clothespin

C. There is a pipe
The knife is above the pipe
The garbage can is above the knife
The tie is to the left of the garbage can
The kettle is below the tie
The ironing board is to the left of the kettle

D. There is a ring
The glass is above the ring
The pineapple is to the right of the glass
The flower is above the pineapple
The light switch is above the flower
The screwdriver is to the right of the light switch

E. There is a hanger
The paintbrush is above the hanger
The cap is to the right of the paintbrush
The spool of thread is above the cap
The onion is above the spool of thread
The drum is to the left of the onion

F. There is a guitar
The watermelon is to the left of the guitar
The frying pan is below the watermelon
The glove is to the left of the frying pan
The cigar is above the glove
The envelope is to the left of the cigar

G. There is a kite
The necklace is to the left of the kite
The trumpet is above the necklace
The stove is to the right of the trumpet
The record player is above the stove
The house is to the left of the record player

H. There is a boot
The hammer is to the right of the boot
The dress is above the hammer
The balloon is to the right of the dress
The axe is above the balloon
The chisel is to the right of the axe

I. There is a broom
The cigarette is to the right of the broom
The box is above the cigarette
The saw is to the left of the box
The nail file is above the saw
The book is to the left of the nail file

J. There is a sock
The sandwich is above the sock
The wineglass is to the left of the sandwich
The rolling pin is to the left of the wineglass
The salt shaker is above the rolling pin
The train is to the right of the salt shaker

Appendix C

Object Imagery Sentences (True/False)

1. An uppercase "n" is composed entirely of lines that are straight ?
1b. An uppercase "n" is composed entirely of lines that are curved?
2. The eraser on the end of a pencil is pink ?
2b. The eraser on the end of a pencil is black ?
3. The symbol for degrees is a tiny circle ?
3b. The symbol for degrees is a tiny asterisk ?
4. The seeds of a watermelon are black ?
4b. The seeds of a watermelon are green ?
5. When papers are stapled together the number of holes in each piece of paper is two ?
5b. When papers are stapled together the number of holes in each piece of paper is three ?
6. The front end of a ski is usually rounded ?
6b. The front end of a ski is usually straight ?
7. Relative to their size, elephants have small eyes ?
7b. Relative to their size elephants have large eyes ?
8. A kangaroo has a long tail ?
8b. A kangaroo has a short tail ?
9. Of the minute and hour hands on a watch the hour hand is shorter ?
9b. Of the minute and hour hands on a watch the hour hand is longer ?
10. The skin of a ripe plum is smooth
10b. The skin of a ripe plum is wrinkled ?
11. The stars on the American flag are white ?
11b. The stars on the American flag are blue ?
12. Compared to the black keys, the white keys of a piano are longer ?
12b. Compared to the black keys, the white keys of a piano are shorter ?
13. Tractors have two very large wheels in the back ?
13b. Tractors have two very large wheels in the front ?
14. A grapefruit is larger than an orange ?
14b. A grapefruit is larger than a cantaloupe ?
15. The tail of a seahorse is curved ?
15b. The tail of a seahorse is straight ?
16. A new pencil is longer than a popsicle stick ?
16b. A popsicle stick is longer than a new pencil ?

Spatial Imagery Sentences (True/False)

1. When a person is standing on his head, his shoulders are closer to the ground than his hips ?
1b. When a person is standing on his head, his hips are closer to the ground than his shoulders?
2. A capital letter "e" is drawn with four lines ?
2b. A capital letter "e" is drawn with five lines ?
3. As you look into a car from the front the driver sits on the right ?
3b. As you look into a car from the front the driver sits in the left ?
4. If the Roman numeral XI is rotated 180 degrees the result is the Roman numeral nine ?
4b. If the Roman numeral XI is rotated 180 degree the result is the Roman numeral eleven ?
5. As you look at books on a bookshelf the low number pages are on your right ?
5b. As you look at books on a bookshelf the low number pages are on you left ?
6. The letter "p" can be rotated 180 degrees to look like the letter "d" ?
6b. The letter "p" can be rotated 180 degrees to look like the letter "b"
7. The Roman numeral "37" is written with six symbols ?
7b. The Roman numeral "37" is written with five symbols ?
8. A standard star has five points ?
8b. A standard star has six points ?
9. On a calculator display the number 5 is composed of 5 straight lines ?
9b. On a calculator display the number 5 is composed of six straight lines ?
10. As you read a book you usually turn the pages from right to left ?
10b. As you read a book you usually turn the pages from left to right ?

11. If the symbol meaning "less-than" is rotated 90 degrees counterclockwise it looks like the letter "V"
11b. If the symbol meaning "greater-than" is rotated 90 degrees counterclockwise it looks like the letter "V" ?
12. A tic-tac-toe game is drawn with four lines ?
12b. A tic-tac-toe game is drawn with six lines ?
13. A right-handed hitter places his left side toward the pitcher ?
13b. A right-handed hitter places his right side toward the pitcher ?
14. On a number line negative ten is left of negative one ?
14b. On a number line negative ten is right of negative one ?
15. To open a jar you turn the lid counterclockwise ?
15b. To open a jar you turn the lid clockwise ?
16. If one is wearing a watch on the left wrist the number "6" is closer to the fingers than the number "9" ?
16b. If one is wearing a watch on the left wrist the number "6" is closer to the fingers than the number "3" ?

Abstract Imagery Sentences (True/False)

1. In our calendar system there are seven days in a week ?
1b. In our calendar system there are seven days in a month ?
2. Biology is a science that studies plants and animals ?
2b. Biology is a science that studies plants and rocks ?
3. In the human lifespan infancy comes before adolescence ?
3b. In the human lifespan adolescence comes before infancy ?
4. The student at the top of the class is best ?
4b. The student at the top of the class is worst ?
5. A country is a political entity that has citizens ?
5b. A country is a political entity that has windows ?
6. In the human species the number of genders is two ?
6b. In the human species the number of genders is three ?
7. Spring is the only season between winter and summer ?
7b. Spring is the only season between winter and autumn ?
8. It takes longer to read a novel than to read a novelette ?
8b. It takes longer to read a novelette than to read a novel ?
9. In a variety of different genres the introduction precedes the conclusion ?
9b In a variety of different genres the introduction follows the conclusion ?
10. Paprika is a seasoning that is used less often than salt ?
10b. Salt is a seasoning that is used less often than paprika ?
11. In a monarchy a prince will one day be a king ?
11b. In a monarchy a prince will one day be a queen ?
12. A pound is a unit of weight that is heavier than an ounce ?
12b. An ounce is a unit of weight that is heavier than a pound ?
13. German Shepherds are often used as watchdogs ?
13b. Toy poodles are often used as watchdogs ?
14. Animals such as deer and elk are stuffed by a taxidermist ?
14b. Animals such as deer and elk are stuffed by a toxicologist ?
15. Geology studies the structure and development of the earth ?
15b Geology studies the structure and development of the planets ?
16. A father is a male who has children ?
16b. A father is a male who buys children ?

Appendix D

True and False versions of each sentence in descending order of reaction time difference for RSVP and spatial presentation formats

Sentence types:(s) spatial, (o) object, (a) abstract

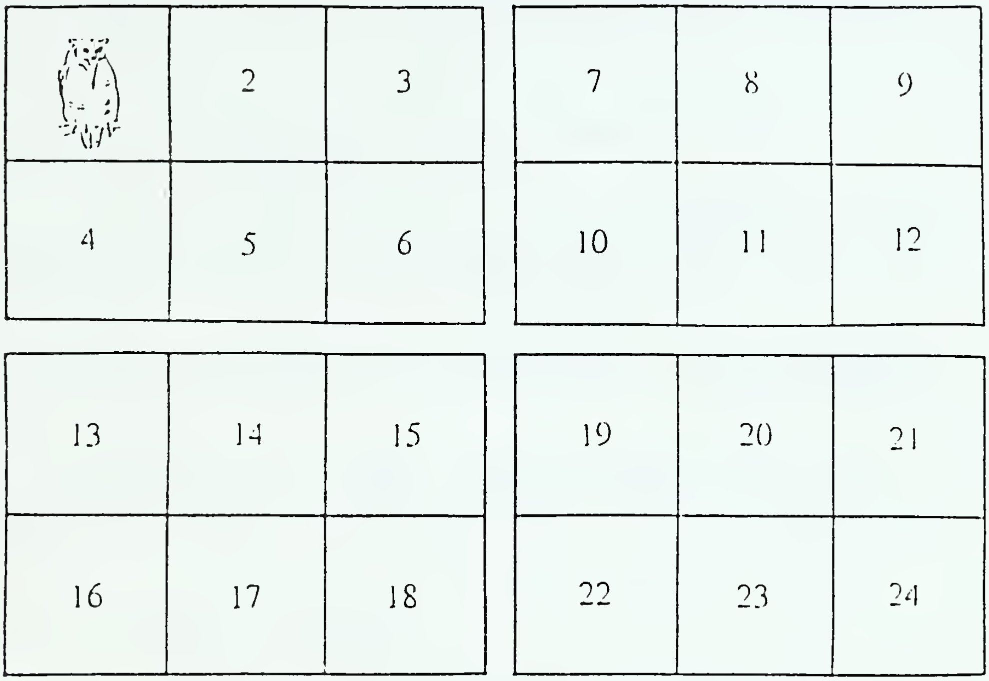
Type	RT difference	
s	981	9. On a calculator display the number 5 is composed of five straight lines ? 9b. On a calculator display the number 5 is composed of six straight lines ?
s	755	10. As you read a book you usually turn the pages from right to left ? 10b. As you read a book you usually turn the pages from left to right ?
s	613	16. If one is wearing a watch on the left wrist the number "6" is closer to the fingers than the number "9" ? 16b. If one is wearing a watch on the left wrist the number "6" is closer to the fingers than the number 3" ?
a	597	7. Spring is the only season between winter and summer ? 7b. Spring is the only season between winter and autumn ?
o	583	14. A grapefruit is larger than an orange ? 14b. A grapefruit is larger than a cantaloupe ?
s	521	6. The letter "p" can be rotated 180 degrees to look like the letter "d" ? 6b. The letter "p" can be rotated 180 degrees to look like the letter "b"
o	512	5. When papers are stapled together the number of holes in each piece of paper is two ? 5b. When papers are stapled together the number of holes in each piece of paper is three ?
s	487	3. As you look into a car from the front the driver sits on the right ? 3b. As you look into a car from the front the driver sits on the left ?
a	481	9. In a variety of different genres the introduction precedes the conclusion ? 9b In a variety of different genres the introduction follows the conclusion ?
s	437	13. A right-handed hitter places his left side toward the pitcher ? 13b. A right-handed hitter places his right side toward the pitcher ?
a	419	2. Biology is a science that studies plants and animals ? 2b. Biology is a science that studies plants and rocks ?
a	397	10. Paprika is a seasoning that is used less often than salt ? 10b. Salt is a seasoning that is used less often than paprika ?
a	384	8. It takes longer to read a novel than to read a

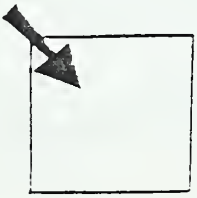
		novelette ? 8b. It takes longer to read a novelette than to read a novel ?
o	376	6. The front end of a ski is usually rounded ? 6b. The front end of a ski is usually straight ?
o	351	3. The symbol for degrees is a tiny circle ? 3b. The symbol for degrees is a tiny asterisk ?
o	350	10. The skin of a ripe plum is smooth 10b. The skin of a ripe plum is wrinkled ?
o	324	15. The tail of a seahorse is curved ? 15b. The tail of a seahorse is straight ?
s	311	14. On a number line negative ten is left of negative one ? 14b. On a number line negative ten is right of negative one ?
o	305	1. An uppercase "n" is composed entirely of lines that are straight ? 1b. An uppercase "n" is composed entirely of lines that are curved?
o	291	2. The eraser on the end of a pencil is pink ? 2b. The eraser on the end of a pencil is black ?
o	281	11. The stars on the American flag are white ? 11b. The stars on the American flag are blue ?
a	280	16. A father is a male who has children ? 16b. A father is a male who buys children ?
a	263	3. In the human lifespan infancy comes before adolescence ? 3b. In the human lifespan adolescence comes before infancy ?
o	246	7. Relative to their size, elephants have small eyes ? 7b. Relative to their size elephants have large eyes ?
o	244	16. A new pencil is longer than a popsicle stick ? 16b. A popsicle stick is longer than a new pencil ?
o	233	9. Of the minute and hour hands on a watch the hour hand is shorter ? 9b. Of the minute and hour hands on a watch the hour hand is longer ?
o	222	12. Compared to the black keys, the white keys of a piano are longer ? 12b. Compared to the black keys, the white keys of a piano are shorter ?
o	218	4. The seeds of a watermelon are black ? 4b. The seeds of a watermelon are green ?
a	194	4. The student at the top of the class is best ? 4b. The student at the top of the class is worst ?
a	182	13. German Shepherds are often used as watchdogs ? 13b. Toy poodles are often used as watchdogs ?
s	166	2. A capital letter "e" is drawn with four lines ? 2b. A capital letter "e" is drawn with five lines ?
s	159	8. A standard star has five points ? 8b. A standard star has six points ?
a	155	6. In the human species the number of genders is two ? 6b. In the human species the number of genders is three ?
a	100	1. In our calendar system there are seven days in a week ? 1b. In our calendar system there are seven days in a month ?
s	78	1. When a person is standing on his head, his shoulders are closer to the ground than his hips ?

		1b. When a person is standing on his head, his hips are closer to the ground than his shoulders ?
s	47	15. To open a jar you turn the lid counterclockwise ? 15b. To open a jar you turn the lid clockwise ?
s	27	12. A tic-tac-toe game is drawn with four lines ? 12b. A tic-tac-toe game is drawn with six lines ?
o	23	8. A kangaroo has a long tail ? 8b. A kangaroo has a short tail ?
a	7	5. A country is a political entity that has citizens ? 5b. A country is a political entity that has windows ?
a	-41	12. A pound is a unit of weight that is heavier than an ounce ? 12b. An ounce is a unit of weight that is heavier than a pound ?
a	-54	15. Geology studies the structure and development of the earth ? 15b Geology studies the structure and development of the planets ?
a	-61	11. In a monarchy a prince will one day be a king ? 11b. In a monarchy a prince will one day be a queen ?
s	-82	4. If the Roman numeral XI is rotated 180 degrees the result is the Roman numeral nine ? 4b. If the Roman numeral XI is rotated 180 degree the result is the Roman numeral eleven ?
o	-146	13. Tractors have two very large wheels in the back ? 13b. Tractors have two very large wheels in the front ?
a	-499	14. Animals such as deer and elk are stuffed by a taxidermist ? 14b. Animals such as deer and elk are stuffed by a toxicologist ?

Appendix E

Sample stimuli for Experiments 3-5 and retrieval cues for Experiment 5





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Biography

Maria Watson was born in New York City on January 18, 1966. She received a Bachelor of Arts with High Honors from Rutgers University in May 1988. She began her graduate training at Duke University in September 1988, and received an M.A in psychology in May 1993. Her awards include a Duke University Graduate School Fellowship and the Edna S. Bissett Dissertation Fellowship. She has accepted a Visiting Assistant Professor position at the University of North Carolina at Greensboro for the 1994-95 academic year.

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